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H AND M MUSCLE TWITCHES OF HUMAN SOLEUS MUSCLE SUBJECTED TO STRENGTH TRAINING

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "H and M Muscle Twitches of Human Soleus Muscle Subjected to Strength Training", submitted by Marcel Nadeau in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Physical Education.

A ma fiancée de toujours, Diane
et à mes fils, Nicolas et
Benjamin auxquels je souhaite un
nouveau monde.

ABSTRACT

Three studies were conducted to relate the contractile properties of the human soleus muscle to muscle strength training of the triceps surae. The first and second studies involved training of eleven male physical education students and four male sedentary subjects and the third study included four male weight lifters. The contractile properties were studied in two types of response obtained by monopolar stimulation of the tibial nerve into the popliteal fossa: the H-response and the M-response. The strength training program consisted of five daily maximal voluntary plantar flexions of the right calf muscles of six-second duration each separated by a fifty-four second rest. The program lasted twenty-five days over a period of five weeks. The gain in muscle strength was shown not to be significant in the physical education students whereas it was showed to be significant in the sedentary subjects. The contraction time, the half-relaxation time and the twitch tension of the H-response (which could only be studied in the physical education students) were not modified by the strength training program. The contraction time and the twitch tension of the M-response of the physical education students and of the sedentary subjects were also not significantly modified by the strength training program. The half-relaxation time, which decreased significantly in the sedentary subjects, tended to show a relationship with training. Hypothesized supraspinal reflex waves following muscle twitches were observed in many physical education students, in one sedentary subject and in one weight lifter. The

presence of these waves thought to synchronize motor units being recruited could not be related to muscle strength training. Therefore, the frequency of firing of motor units may have increased as a result of the training of the sedentary subjects.

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INTRODUCTION

Weight lifting has always been a challenge to people who are interested in knowing how much they or others can lift. Muscle strength, though defined as the maximum force a muscle (or group of muscles) can exert, is to a certain extent unpredictable on a day to day basis.

Ikai and Steinhaus (1961) conducted experiments with subjects doing a maximal arm flexion every minute over a thirty minute period. They found that various stimuli applied 2 to 10 seconds before a pull, including a gunshot, a shout, various drugs or hypnosis could significantly modify the maximal exerted strength. Thus, the performance was distinctly higher after the gunshot than before. Shouting, hypnosis, epinephrine or amphetamine also tended to improve performance over controls. The positive effect on strength was noticeable in untrained subjects, but was slight or absent in well-trained athletes. Ikai and Steinhaus (1961) cited Pavlov: " ... any unusual sensory experience or excitement may inhibit inhibitions": They emphasized that their findings "... support the thesis that in every voluntarily executed, all-out maximal effort, psychological rathern than physiological factors determine the limits of performance".

It is a well-known phenomenon that an individual can become expectionally more powerful than normal in a stress situation. In controlled experiments (Astrand and Rodahl, 1970), it was established that catecholamines increase both excitability and contractility of muscle, but the mechanism through which this occurs is not clear. In Astrand and Rodahl's opinion

(1970), there is overwhelming evidence showing that a voluntary maximal muscle effort in most situations with unconditioned subjects does not engage as many motor units of the active muscle as are engaged during maximal tetanic stimulation. Supraspinal and proprioceptive activity inhibit to varying degrees some motoneurons. Specifically in an emergency situation, or perhaps as an effect of training, inhibition decreases (or facilitation increases), and the muscle mass can become more completely utilized in contraction.

From these studies, it is clear that outside factors can substantially modify the development of strength in the absence of muscle strength training. These factors evidently act through the nervous system. One draws from these observations that maximum performance is modified not solely by physiological but as well by psychological factors. It is possible to avoid the psychological artefact on muscle strength development by the use of electrical stimulation. Electrical stimulation can be applied to the muscle itself or to the nerve supplying the muscle. Nerve stimulation better approximates physiological conditions because the impulses have to follow the branching of the nerve before arriving at the neuromuscular junction. The Hoffman technique (1918) as standardized by Hugon (1973) consists of stimulating the tibial nerve in the popliteal fossa eliciting responses from the soleus muscle. Using this technique, two types of response have been described. The H (Hoffman) response is the muscle response to stimulation of the afferent fibers monosynaptically connected to the alpha motoneurons innervating the soleus muscle. The M (motor) response is that muscle response to stimulation of the efferent fibers innervating the soleus muscle.

Tension produced by a muscle group depends upon the number and kind of motor units activated. The frequency at which they are stimulated,

and the synchrony of recruitment (Edington and Edgerton, 1976). The number and kind of motor units activated is reflected in the twitch tension of the M-response because it could parallel the maximum voluntary tension. The frequency at which motor units are stimulated is as well reflected by the contraction time of the M-response. The synchronous firing of motor units is caused by a feedback mechanism (Milner-Brown et al., 1975) and could be studied using the reflex H-response technique.

Purpose of the study

It appears that the change in muscle strength development through training is not only a result of the modification of the muscle itself, but rather of the "training" of the neuromuscular system as a whole. Animal experimentation relating the contractile properties of any muscle group pre- and post-training reveals that specificity in training is very important. A specific training program elicits a specific response. The magnitude of this response may be different for different individuals depending upon muscle fiber composition, sex and age.

There has been no work reported evaluating the modifications of the contractile properties of the soleus muscle in human subjects undergoing a specific isometric muscle strength training program.

The purpose of present research was to study the effects of muscle strength training on voluntarily induced muscular contractions (maximal static plantar flexions) in the triceps surae and electrically induced muscular contractions (H- and M- responses or muscle twitches) in the soleus muscle.

Data from the present research will, it is hoped, provide insight into changes in the contractile properties of muscle as a result of training.

A modification in the contraction time of the H-response and M-response may indicate a change in the frequency of discharge of slow-twitch motor units and this being possibly related to synchrony of recruitment. A reduction in the twitch tension of the H-response may indicate a conversion of slow-twitch to fast-twitch motor units. An increase in the twitch tensions of the M-response may substantiate the conversion of slow-twitch to fast twitch motor units or an enlargement of muscle fibers in fast twitch motor units. No modification in both responses may indicate that the frequency of discharge of motor units is possibly responsible for the increase in maximal voluntary muscle tension and at the same time being not related to the contraction time of the motor units.

A comparison of sedentary subjects with more active subjects (physical education students) may indicate the trainability of both groups with respect to a specific muscle strength training program on a short-term basis. Evaluation of the contractile properties of olympic style weight lifters who use the soleus during their sport may allow a comparison between short-term training and long-term training of the human soleus muscle.

CHAPTER I

RELATED LITERATURE

1. Strength training

A. Hypertrophy

The classical studies on the response of muscle to training are those of Morpugo and Siebert. Morpugo (1897) removed the sartorius muscle from one leg of each of two dogs and then exercised the animals on a treadmill for two months. He found that the corresponding intact sartorius muscles increased in size, but showed no increase in the number of muscle fibers or their length. He concluded that hypertrophy was caused by an increase in the amount of sarcoplasm. Siebert (1928) found that hypertrophy resulted from an increase in the intensity of work done and that the total amount of work was without significance. Only when a muscle is overloaded does it hypertrophy.

Rash (1969) observed: "high-repetition, low resistance exercises, such as distance running, do not ordinarily produce hypertrophied muscles whereas low-repetition high resistance exercises, such as weight training, do". Gordon et al. (1967) attributed hypertrophy resulting from endurance training to increased concentration of energy liberating enzymes (sarcoplasmic proteins). Strength training on the other hand increases the concentration of actomyosin filaments (myofibrillar proteins). They concluded that the careful investigator must differentiate between sarcoplasmic hypertrophy, resulting from prolonged

repetitive exercise, and actomyosin hypertrophy, resulting from brief, forceful exercise.

B. Isometric muscle strength training

Most investigators have evaluated the "trainability" or speed of increase of strength of muscles as a percentage of the initial value. If this rate did not change in the course of training, strength would be expected to increase progressively. In 1963, Kirsten analyzed the curve of the increase of strength with time during standard training (one short maximal contraction daily on successive days) on 143 boys and girls between 11 and 16 years of age. He had the subjects train their trunk extensors from a fixed flexed position for eight weeks. He observed that the rate decreased for two-thirds of the children and increased for only one-tenth. The quarter of the children showing a linear rise had a low initial strength. Figure 1 shows that in such cases a linear increase in strength is the rule. It follows from these results, that the same training stimulus has a weaker effect in the advanced state of training.

Based on these results, Muller and Rohmert (1963) further calculated for 88 of those children how many weeks it took to increase relative strength from 75 to 80 percent, from 80 to 85 percent, from 85 to 90 percent, and so on. From this they derived the average rate of increase in strength for each 5 percent of relative strength (Table 1). Figure 1 shows the increase in relative strength as a function of training time and the rate of increase as a function of relative strength. Only the part of the curve above 75 percent of relative strength is based on Kirsten's data (1963); the remaining portion of the curve is projected from the results of Muller and Beckman (1966), who found that children with paretic muscles below 10 percent

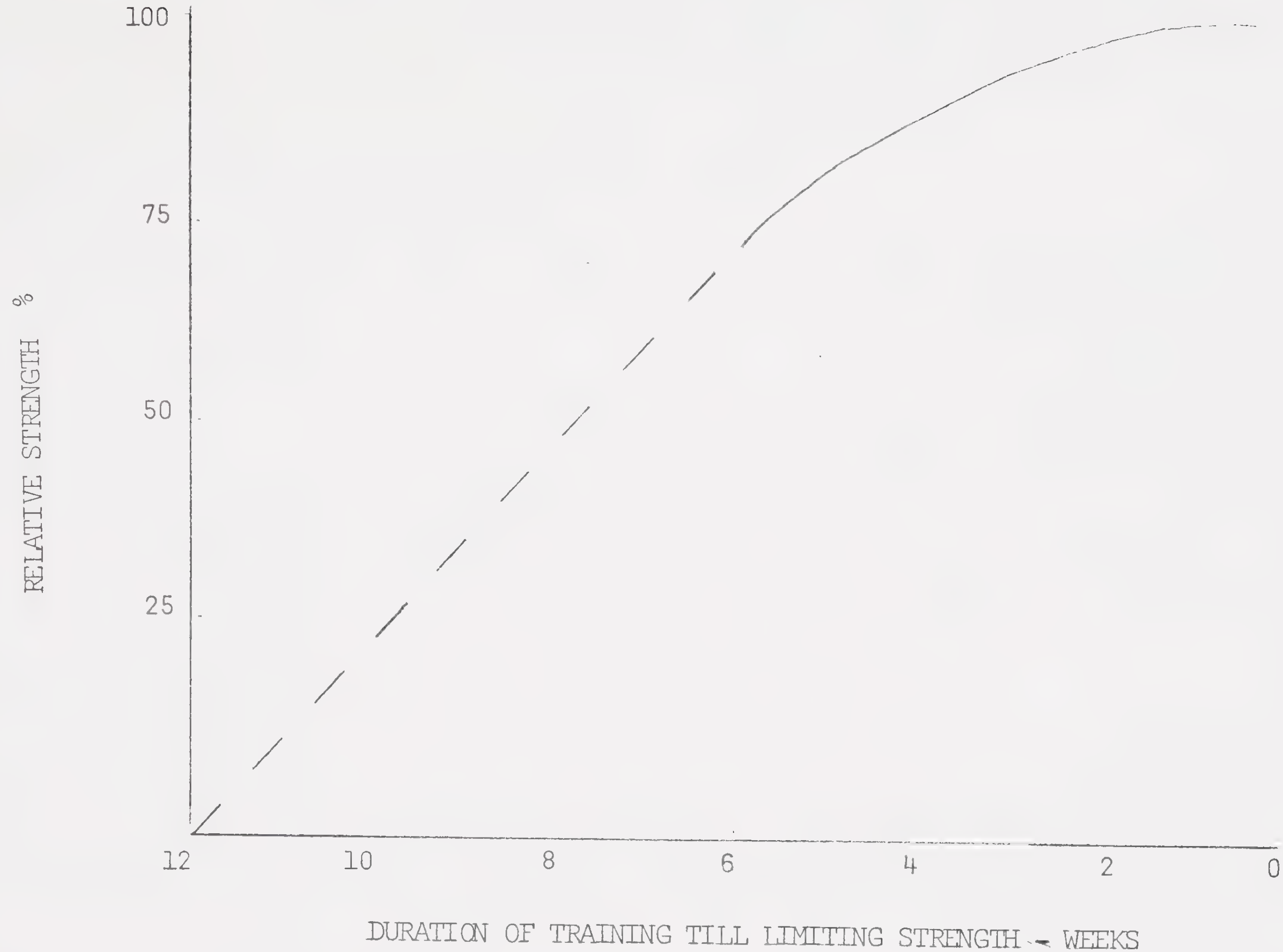


Fig. 1. Course of increase in relative muscle strength up to limiting strength caused by isometric training (one daily maximum contraction) (Muller, 1970)

TABLE 1. Increase in relative strength of boys and girls during standard training (Muller, 1970)

Initial relative strength	Increase in relative strength per week	
	Boys	Girls
%	%	%
75 - 80	9.0 ± 3.0	9.1 ± 3.5
80 - 85	7.9 ± 3.0	8.1 ± 2.9
85 - 90	6.2 ± 2.5	6.9 ± 2.7
90 - 95	4.4 ± 1.5	5.0 ± 2.1
95 - 100	1.9 ± 0.6	2.0 ± 0.8

in relative strength required 10 to 12 weeks to reach their limiting strength. The time for training from zero percent up to limiting strength was, therefore, set at 12 weeks in Figure 1 and the curve drawn to fit. Before the slope of the curve was known (12 percent per week), the original report of Hettinger and Muller in 1953 that isometric training with one short daily maximum contraction could be successful was reinvestigated by many authors, some of whom confirmed it while others did not (see Hettinger, 1961; Muller 1970). It is now clear that the latter trained subjects in a high state of training near limiting strength. From his related literature, Muller (1970) also concluded that training of muscles from a given relative strength up to limiting strength with standard training i.e. one maximal daily contraction of one second's duration, follows a course which is not influenced by age, sex, muscle group or the final height of limiting strength.

Muller (1970) stated the advantages of standard training:

1. For maximal contraction no dynamometer is needed. A maximal contraction can be exerted against any immovable resistance. A dynamometer is necessary, however, in order to follow the increase in strength during training.
2. Since one second can be estimated with sufficient accuracy, a stop watch is not required.
3. One contraction per day requires little time and is as effective as training requiring more time.

Figure 2 shows that with standard training, the limiting strength will be attained but slower than if maximum contractions are held once for 6 seconds or in multiple fashion totaling 30 seconds.

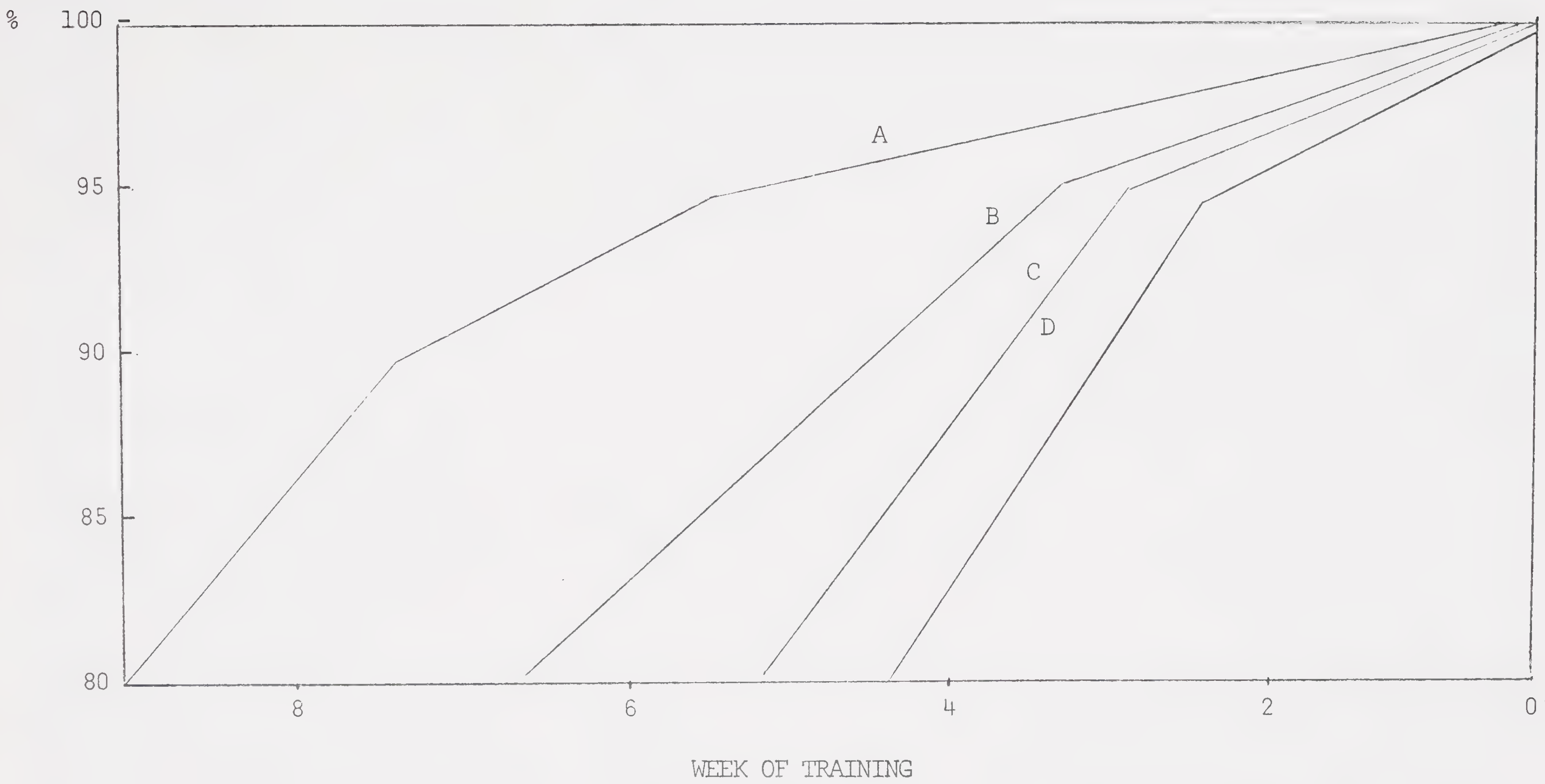


Fig. 2. Weeks needed to reach limiting strength from an initial relative strength of 80 percent; A, by submaximal training (one daily 65 percent maximum contraction); B, by standard training (one daily maximum contraction of one second); C, by one daily maximum contraction of 6 seconds; D, by multiple daily maximum contractions totaling 30 seconds in duration (Muller, 1970).

2. Muscle fiber types in the soleus motor units

A motor unit is made of several muscle fibers innervated by a single branching motoneuron. Edström and Nyström (1969) took biopsy specimens from the biceps brachili, the vastus lateralis, the tibialis anterior, the soleus and the lateral head of the gastrocnemius and they found that all of the studied muscles were mixed; i.e., they contained both red and white muscle fibers. Rasch (1969) defined the red fibers as tonic fibers with relatively large amounts of myoglobin giving them a redder appearance than the white fibers which are phasic and have very little myoglobin. The red fibers depend primarily on oxidative metabolism (B- oxydation of fatty acids, citric acid cycle) and are adapted to sustained (tonic) contraction, such as required in maintaining posture. The white fibers depend primarily on glycolytic metabolism and are better adapted to perform fast (phasic) contractions. On the basis of stainability for myofibrillar ATPase the red fibers have low ATPase activity whereas white fibers have high ATPase activity (Padykula and Herman, 1955; Fenichel and Engel, 1963; Edström and Nyström, 1969; Rasch, 1969). However, the classification of muscle fibers into red and white with low and high myofibrillar ATPase activity respectively does not hold anymore since in their recent and extensive paper on the motor units properties, Burke and Edgerton (1975) classified the mammalian motor units into two broad classes on the basis of mechanical properties of their muscle units: fast twitch (white) and slow twitch (red). On the basis of biochemical properties, these units could be divided into three distinct classes: 1) high glycolytic, low oxidative, 2) high glycolytic, intermediate oxidative and 3) low glycolytic and high oxidative. Combining these two classifications, they characterized three types of motor units: FG, a fast twitch unit with a predominantly glycolytic metabolism; FOG, a fast twitch unit using both oxidative and glycolytic metabolism

and SO, a slow twitch unit depending premarily upon oxidative metabolism.

To this classification, Close (1972) and more recently Prince et al. (1976) associated the Roman numeral nomenclature of Dubowitz and Pearse (1960) and of Engel (1962) and of Brooke and Kaiser (1970). The SO units correspond to the type I units; the FOG units correspond to the type IIa units and the FG units correspond to the type IIb units.

Using human necropsy material, Susheela and Walton (1969) found that in the soleus muscle, the red (SO units) fibers predominated and Jennekens et al. (1971) also found this predominance of red fibers in the gastrocnemius, but to a lesser extent.

With biopsy samples from the gastrocnemius and the soleus, Gollnick et al.(1974 b) correlated fiber composition and enzymes profiles. Based on the histochemical display of myofibrillar ATPase staining, the muscle fibers were divided into two groups. The soleus muscle contained predominantly (80%) slow twitch (SO type) fibers. The mean value for SO units in gastrocnemius muscle was 57%. Glycolytic enzyme activities were lower in the predominantly SO units as compared to samples with many fast twitch fibers (FG units).

3. Factors controlling muscle strength

The amount of tension that a muscle can exert is related to the muscle length at the time of the isometric contraction (Edington and Edgerton, 1976). Indeed, Gordon et al. (1966) have demonstrated that the amount of overlap between the actin filaments and the myosin filaments was related to the amount of tension developed in a muscle fiber during a tetanic contraction. However, from rest to maximal voluntary contraction there is an orderly recruitment of motor units (Milner-Brown et al., 1973; Burke, 1973; Hannerz, 1974; Burke and Edgerton, 1975), which follows the spectrum of motoneuron size

("size principle", Henneman and Olsen, 1965): the smallest motoneurons are recruited first and the largest motoneurons are recruited last (Burke and Edgerton, 1975). However, in voluntary contraction, the motor unit recruitment cannot be dissociated from the frequency of discharge of the motoneurons to explain the increase in muscle tension. Hannerz (1974) has shown that the higher the threshold of the motor unit in sustained contraction, the higher was the frequency when the unit attained a discharge at regular intervals and the higher the maximum frequency tended to be. Whether several motor units are synchronously or asynchronously activated is an important determinant of the tension produced (Edington and Edgerton, 1976). Milner-Brown et al. (1975) observed that during voluntary muscle contractions, motor units appeared to fire independently of one another and that after training some subjects in increasing their muscle strength, increased significantly the level of synchronization.

The orderly patterns of motoneuron recruitment is, as summarized by Burke (1973), due largely to the organization of synaptic input favoring firstly the SO units and then finally the FG units; nonetheless this order may vary under a variety of conditions. Wagman et al. (1965) observed that the order of unit recruitment could vary with the position of the limb during testing; Hannertz (1974) observed considerable changes in recruitment order of motor units following a change from sustained to twitch contraction. The type of activity performed e.g. isotonic (such as running or pedaling) or isometric also affects the recruitment of motor units to meet the output demanded. During isotonic exercises, Piehl (1974) reported that a preferential depletion of glycogen from fast twitch fibers was not evident unless a work load greater than 90% of VO_2 max was performed. During isometric contractions, Gollnick et al. (1974 a) observed that there was a selective loss of glycogen in slow twitch

fibers when the tension was less than 20% of the maximum, while there was a relatively greater loss of glycogen in fast twitch fibers when the tension was greater than 20%. Finally, Granit (1975) reported that when phasic motoneurons (innervating fast twitch fibers) are selectively mobilized in fast acts, they could be capable of suppressing the activity of the tonic ones (innervating slow twitch fibers). The mechanism would involve coactivation of the alpha and gamma motoneurons, thus increasing the firing rates of spindles in rough proportion to the voluntary effort and forming a disynaptic circuit from the spindle afferents across a recurrent fiber to a Renshaw cell inhibiting the motoneuron (Granit, 1975).

4. Parameters of a muscle twitch

A muscle twitch is the contraction of one or several motor units following a single impulse delivered to its motor axon (s). The peak tension is the maximum tension developed by the muscle fibers during the twitch. The contraction time is the time from the deviation from the isoelectric line to reach the peak tension (Buchthal and Schmalbruch, 1970 b). The half-relaxation time is the time taken from the end of the contraction time to the point in relaxation where the tension is half of the peak tension.

The posterior tibial nerve which innervates the triceps surae is a mixed nerve, i.e. with efferent and afferent fibers. If one electrically stimulates the tibial nerve in the popliteal fossa, two muscular responses can happen: one within 10 msec which is the result of efferent fiber stimulation and the other, between 20 and 40 msec after the electrical stimulus, which is the result of afferent fiber stimulation sending its impulse to the spinal cord which excites motor neurons; the motor neurons then command a muscle contraction. The short latency response is called the M-response and the longer

latency response is named the H-response. It is thus possible to obtain two muscle twitches with different mechanical characteristics from the same muscle (Buchthal and Schmalbruch, 1970 b).

5. Animal data

A. Fast and slow twitch muscle

Sica and McComas (1971) reported that individual mammalian motor units can be differentiated in terms of the velocities of their isometric twitches into "fast" and "slow" types. They also reported that the twitch characteristics of an entire muscle depend on the proportions of fast and slow motor units within that muscle.

In Bagust's experiments (1974), mean conduction velocity to cat soleus motor units was 66.1 m/sec and 85.1 m/sec whereas the mean contraction time of the motor units was 77.9 msec and of the parent muscle was 75.6 msec. Correlations for these two parameters varied in 4 experiments between -0.42 ($P < .10$) and -0.86 ($P < .001$), meaning that the higher the conduction velocity the shorter is the contraction time. Correlations of 0.51 ($P < .001$) and of 0.70 ($P < .001$) were found between contraction times and twitch-tetanus ratios, meaning that the faster contracting motor units exhibited the lowest twitch-tetanus ratios.

B. Myosin ATPase and exercise

Bagby et al. (1972) subjected male rats to endurance and sprint training for eleven weeks. They did not observe any significant change in myosin ATPase activity over that period. They explained this result by arguing that the percentage of slow twitch fibers in the assayed gastrocnemius was so small that even if they would have all become fast-twitch fibers the increase

in myosin ATPase activity would not have been more than 10%.

Syrovy et al. (1972) attempted to reproduce in trained swimming rats the findings of Barnard et al. (1970) who had found no modification in the myosin ATPase activity of guinea pig gastrocnemius after 18 weeks of training on a treadmill. They studied the extensor digitorum longus muscle (mainly fast twitch motor units) and the soleus muscle (predominantly slow twitch motor units) (Close, 1972). They observed a 17% increase of ATPase activity of myosin of the soleus in the younger trained rats, but no change for the same activity in the older trained rats. For both groups, there was not any change in this activity of the extensor digitorum longus. They also registered an increase in the percentage of type II fibers (FOG and FG units) in the younger trained rats, and pointed out that if an increase in the myosin ATPase activity was to be looked for, the age and the relative amount of type I fibers (SO units) had to be taken into account.

C. Contractile properties and training

Recently, Fitts et al. (1973) evaluated the contractile properties of the tibialis anterior muscle of miniature pigs which were trained for a period of seven months. The contraction time, the half-relaxation time, the twitch tension, the tetanus tension and the twitch-tetanus ratio of this fast twitch muscle were not statistically different in the three groups: control, sprint training, endurance training. They concluded that physiological exercise appears to have little direct effect on the isometric contractile properties of the muscle.

In their experiments on high intensity training with female rats Staudte et al. (1973) studied the contractile properties of the soleus

(slow-twitch) and of the rectus femoris (fast-twitch). Statistically significant changes were observed for the contraction time and maximum tetanic tension of the soleus muscle but not for the rectus femoris. Contraction time decreased by 15% and tetanus tension, increased by 18%.

Using a specially designed apparatus, Exner et al. (1973) were able to isometrically train rats. Training was accomplished by attaching weights (90 to 200 g) to the tail of the rats.

Female rats were first studied. Soleus muscle became slower by 20% and rectus femoris became faster by 20%. Maximum tetanic tension was only increased in the rectus femoris (increase of 20%). They could not explain the lack of increase in strength of the soleus muscle in light of fiber typing alone: the biomechanical advantage is not the same for both muscles. In their second paper, dealing with male rats (Exner et al., 1973), the 35 days of isometric training yielded different results. Isometric twitch contraction time did not change in either muscle and maximum tetanic tension increased by 6% only in the fast muscle ($P < 0.05$). They attributed the non-responsiveness of contraction time to age: male rats were younger.

6. Human data

A. Fast and slow twitch muscles

Sica and McComas (1971) observed that if the muscle (extensor hallucis brevis) was stretched (plantar flexion of the great toe), the twitch tension would rise in a parallel fashion in young subjects. They also detected a small difference related to sex: the twitches of male subjects tended to be stronger than those of the female subjects. The histogram of contraction times for motor units reveals a bimodal distribution, one mode ranging from 35 msec to 74 msec (fast), the other ranging from 78 msec to 98 msec (slow).

But the histogram of contraction times for whole msucle only shows a skewed distribution to the left, with a mean at 63.4 msec $\pm$ 8.2 msec. They did not find a correlation between the speed of contraction and the twitch tension of a motor unit.

Hanson (1974) performed in vitro experiments on human external intercostal muscles at body and at room temperature. The twitch was two to three times slower at room temperature while the developed twitch peak tension was approximately the same. He computed a correlation coefficient of 0.79 between the percentage red fiber content of the preparation and the contraction times ($P < .15$). A coefficient of correlation of 0.81 ($P < .15$) was found between the half-relaxation times and this percentage content. Mean contraction time was 78.8 msec and mean half-relaxation time was 138.9 msec. From comparisons to rat intercostal muscles, he hypothesized that myofibrillar ATPase activity was not the only factor regulating the contraction speed. The Ca^{++} released from the sarcoplasmic reticulum could be another factor.

In 1970 (a), Buchthal and Schmalbruch recorded in normal human muscle twitches from bundles of fibers of the gastrocnemius, of the soleus, and of the biceps brachii. Most of the fibers (90 - 95%) of the gastrocnemius and of the soleus had contraction times longer than 60 msec. For the biceps brachii only about one third of fibers had contraction times longer than 60 msec. Histochemically, they related fibers with slow contraction times to the fibers rich in mitochondria whereas the fast contraction time fibers corresponded to fibers with a poor or medium amount of mitochondria.

They also noted, that for the biceps brachii, the mean contraction times and standard deviation were the same in males and females (51.4 $\pm$ 1.1 msec for males and 56.2 $\pm$ 2.1 msec for females) and independent of the subject's age (16 - 23 years). They finally observed a dependence on muscle temperature:

the contraction time of fast fiber bundles decreased by 10% per °C and of slow fiber bundles, by 7% per °C, between 22 and 32°C. Above 32°C the decrease was 5% per °C in fast and 4% per °C in slow fiber bundles.

In a subsequent paper (Buchthal and Schmalbruch, 1970 b) muscle fiber bundles of normal human soleus were activated through the tibial nerve to record M- and H-responses and directly with needle electrodes implanted in the belly of the soleus. The contraction times of weak reflex responses in the soleus muscle were about 30% longer than those of the M-response ($P < .001$). Contraction time of reflex twitches was 98 ± 2 msec, of M-twitches 71 ± 2 msec and of response to stimuli in the end-plate zone 76 ± 2 msec. The contraction time decreased slightly with increasing force of the H-reflex ($P < .05$) and, conversely, the contraction time of M-response increased with increasing force ($P < .001$). From their experiments, they concluded that on the soleus muscle of human subjects, only the slower fibers within the muscle contributed to the reflex twitch. In his paper on the central nervous system control of fast and slow twitch motor units, Burke (1973) reported the same findings i.e. that slow twitch fibers were mainly if not predominantly activated by Ia fibers arising from the muscle spindles.

B. Contractile properties and exercise

In 1967, de Jong and Freund electrically stimulated the ulnar nerve at the wrist to relate EMG activity to tension development in the twitch of the adductor pollicis brevis. As the intensity of motor nerve stimulation was increased, evoked potential amptitude and tension increased. The correlation coefficients for individual subjects (10 to 20 observations each) ranged from 0.97 to 0.99 ($P < .001$). Hugon (1973) showed the same results with normal human subjects in whom the H- and M-responses were elicited. However,

he mentioned that strict conditions had to be met in order to keep this relationship of force and EMG amplitude: the foot must be in slight dorsi-flexion in order to stretch the soleus; the knee is flexed at 120°; the maximal M-response must represent the activity in the soleus muscle alone; this can be ascertained by checking whether the M- and H-responses do present a similar configuration (muscle action potential).

Hénane and Macarez (1972) studied the effects of physical exercise on spinal reflectivity in man. H- and M-waves were modified by physical activity according to two criteria: the relative workload and elapsed time following exercise. They claimed early and late depression or potentiation of the H and/or M-responses following submaximal and/or maximal exercise but looking at their data, there did not seem to be any statistical differences at all.

Buchthal and Schmalbruch (1970 a) remarked that the state of training did not alter the average and the range of contraction times. In a weight lifter, whose force was more than twice that of untrained subjects, the spectra of contraction times in the brachial biceps and triceps muscle were within the limits of untrained subjects.

Very recently, Milner-Brown et al. (1975) conducted a study on synchronization of human motor units. The reflex activity of the first dorsal interosseus muscle was studied. The H-wave, as compared to the maximal M-response was not statistically larger among weight lifters and a six-week isometric training of the thenar muscles of healthy subjects did not bring a significant change in the H-reflex.

CHAPTER II

METHODOLOGY

APPARATUS

1. Biomechanical table

The table which the subjects used for training and testing purposes was the table used in biomechanics to determine static muscle strength. A plinth clamped onto the table was designed to create an angle of 120 degrees between the posterior faces of leg and thigh (Hugon, 1973) and to support the upper part of the body as well (Figure 3). This plinth could be moved backward and forward to accomodate different lower leg lengths. The height of the plinth was designed to fit thigh lengths of 1.50 meter subjects; three-centimeters blocks could be added under the plinth in order to accomodate 2 meter subjects.

2. Foot pedal

To ensure isometric muscle contractions of the calf muscle when training and being tested, the foot was inserted into a hockey boot fixed onto a metal plate used as a slider fitting on the foot pedal (Figures 3, 4 and 5). The boot position was adjusted until the axis of rotation of the ankle coincided with the axis of rotation of the foot pedal and was held at that position by a penetrating rod pressing against the slider (Figure 5).

The foot pedal was supported by a frame which was itself supported by another metal frame secured to the table (Figure 3). The foot pedal was oriented at 90 degrees with respect to the floor in order to maintain the

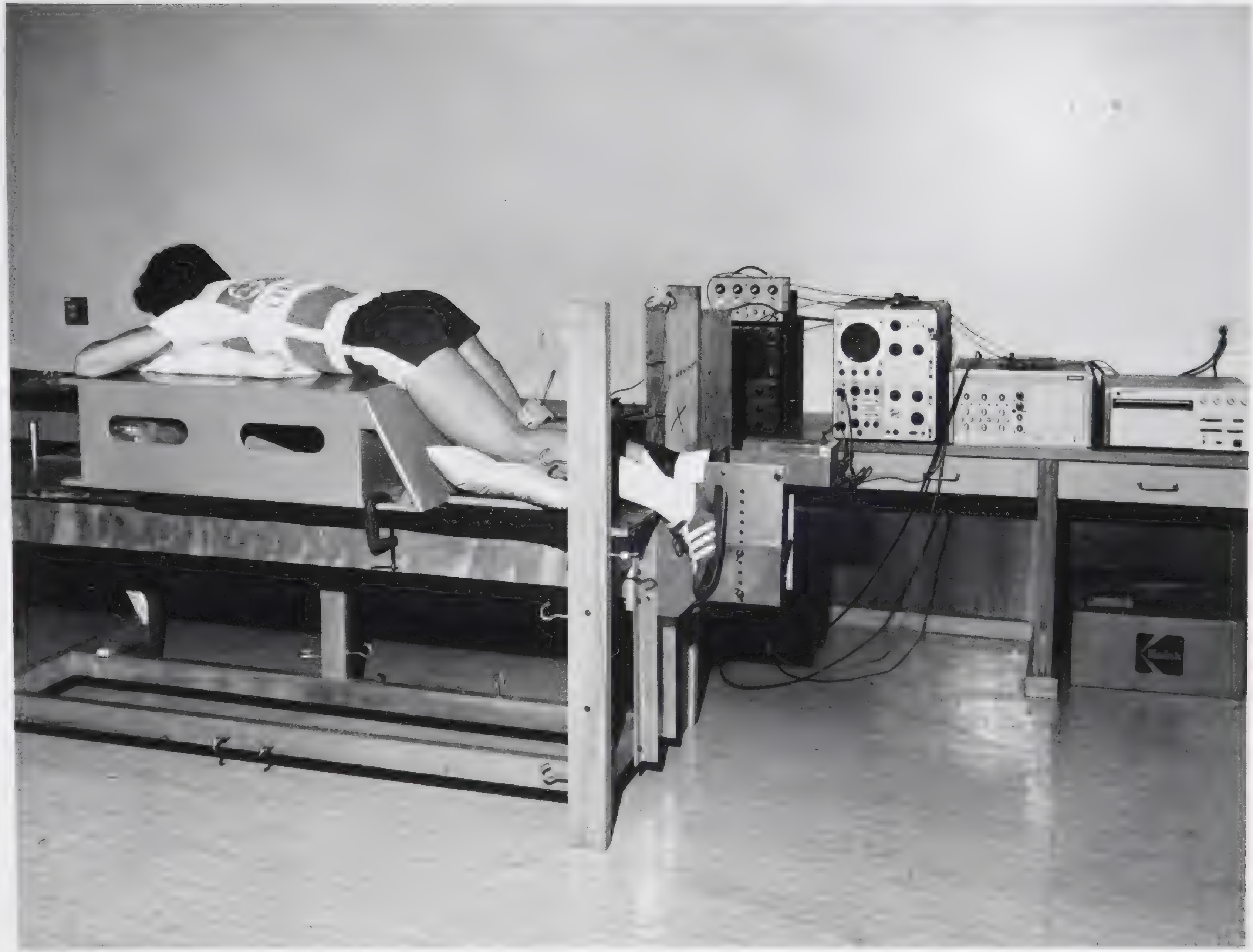


Fig. 3. Biomechanical table and plinth.

Fig. 4. Boot and slider.

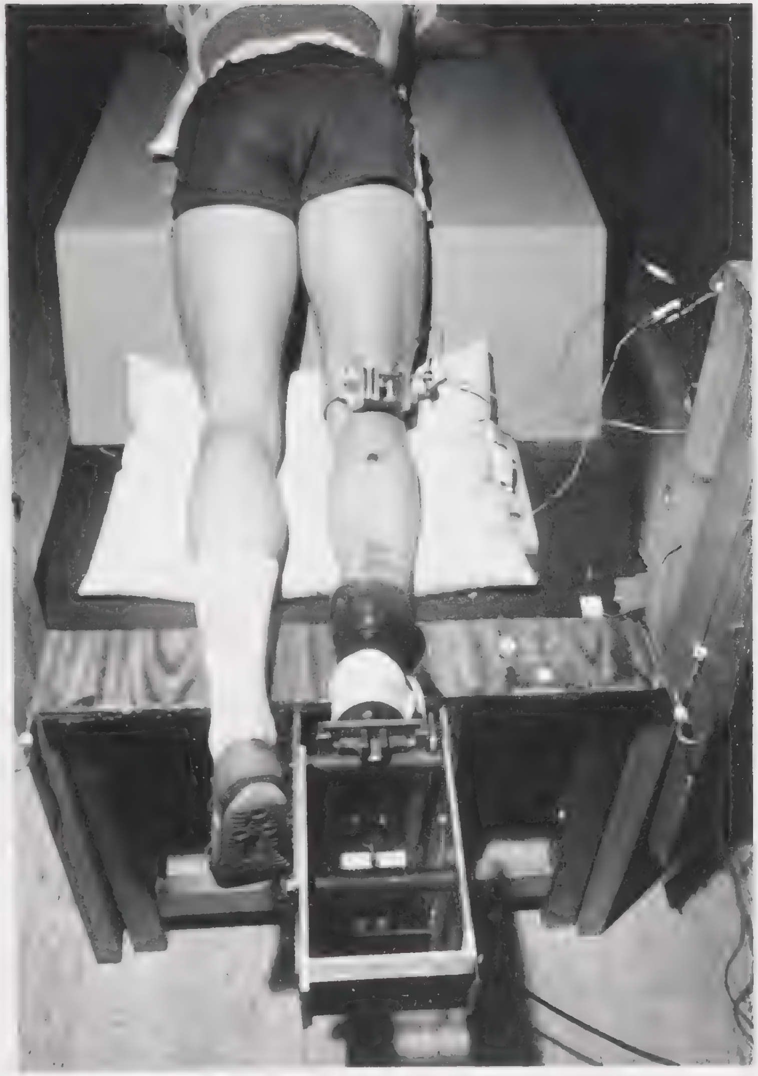


Fig. 5. Foot pedal.

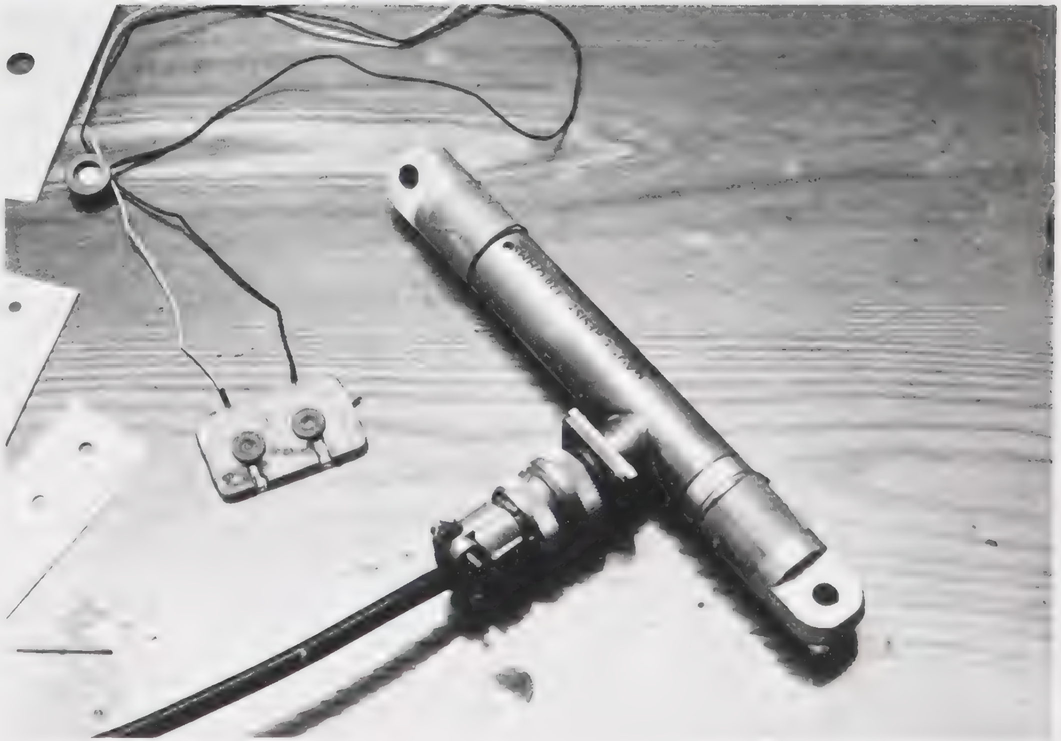


Fig. 6. Load cell.

foot in slight dorsiflexion (Hugon, 1973); its lower extremity received one end of the load cell which runned parallel to the floor; the other end of the load cell was braced against the legs of the biomechanical table.

3. Load cell

A. Description

The tension load cell (Figure 6) used was manufactured by the Aeronautical Division of the National Research Council of Canada. It was six-inch long with with a one-inch diameter. The load cell was maintained in between the lower end of the foot pedal and the table by screwed fittings on each end that plugged into the forks of the foot pedal and table. The load cell was located twelve inches down the axis of rotation of the foot pedal.

B. Calibration

Calibration of the load cell was done and checked before and after the five-week training program. After removing it from its attachments of the table and foot pedal, it was hung down from the ceiling and dead weights up to 300 pounds were added stepwise. The strain was measured by a strainsert transducer/strain indicator Model HWI - D; it was linear with a slop of 17.5 pounds per micro-inch of strain per hundredth of an inch (Appendix A).

To find the transducer calibration factor, a ten-volts escitation was sent to opposite poles of the wheatstone bridge. The signal was then picked up for weights of 20 and 200 pounds respectively by a voltmeter. Both weights gave a calibration factor of three microvolts per pound.

4. Bridge amplifier

A. Description

The model used was a Honeywell Accudata 218-2. It provided all necessary controls for the excitation, balance (automatic) and calibration of straingage transducers, as well as signal amplification(Figure 7).

B. Operation

With a 10 volt DC guage excitation voltage and a wide-band low-pass cutoff filter frequency, amplification was set for testing purposes to bring about a deflection of 10 pounds per inch on the eight-inch wide ultra-violet light sensitive paper (Kodak Linagraph II) of the oscillographic recorder. With a ruler graduated in fortieth of an inch, precision of measurement was down to 0.25 pound.

For training purposes, amplification was reduced by a factor of 5, thus bringing a deflection of one inch for each 50 pounds added. Precision of measurement was therefore set at one pound.

5. Biomedical amplifier

A. Description

The amplifier used for electromyographic recordings was an Honeywell Accudata 135 A (Figure 7). It was a capacitance coupled AC amplifier.

B. Operation

With the Accudata 135 A filters set at 50 Hz (low) and 2.5 KHz (high), the sensitivity of the amplifier was selected to be 4 MV/FS (millivolts full scale) for the H-response and 10 MV/FS for the M-response.

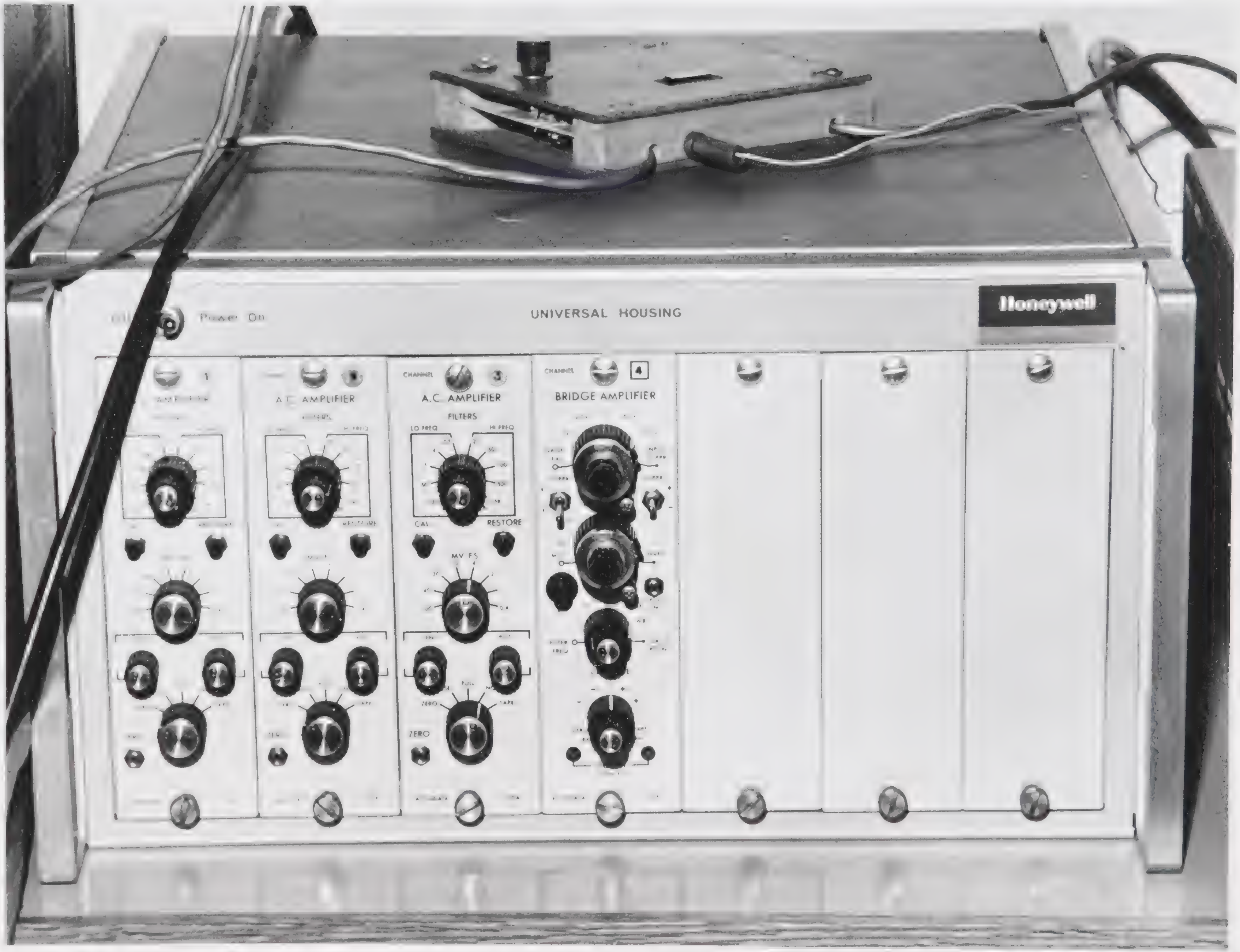


Fig. 7. Amplifiers

C. Electromyographic electrodes

Miniature Beckman electrodes (11 mm diameter) embodied at two centimeters one from the other (Hugon, 1973) in a plastic plate were used as pick-up electrodes (Figure 6). The ground electrode was a standard Beckman electrode (16 mm diameter). Beckman conductive paste was used for better conduction and appropriate adhesive collars of Beckman were used to stick the electrodes onto the skin over the soleus muscle.

6. Oscillographic recorder

A. Description

Signals amplified by the accudata 135 A and the Accudata 218-2 were recorded by an Honeywell Model 1508 B Visicorder Oscillograph. It was a direct-writing oscillograph which records on light-sensitive paper up to 24 channels of data at frequencies from DC to 25 KHz (Figure 8).

B. Operation

For testing purposes, the recorder was driven by an external source (the stimulator) at a speed of 500 centimeters per second. An automatic record timer stopped the recording after 0.7 second. A pushbutton on a relay circuit (designed and mounted by Gilles Lessard; Appendix B; Figure 7) had to be depressed after each recording to allow the following stimulation to be recorded, i.e. to drive the recorder. Time line intervals were set at 10 milliseconds, thus giving a precision of measurement of 1 millisecond for each 0.5 millimeter.

For training purposes, the recorder was removed from its external source in order to be driven manually five seconds before the subjects exerted their maximal muscle contractions. The automatic record timer was

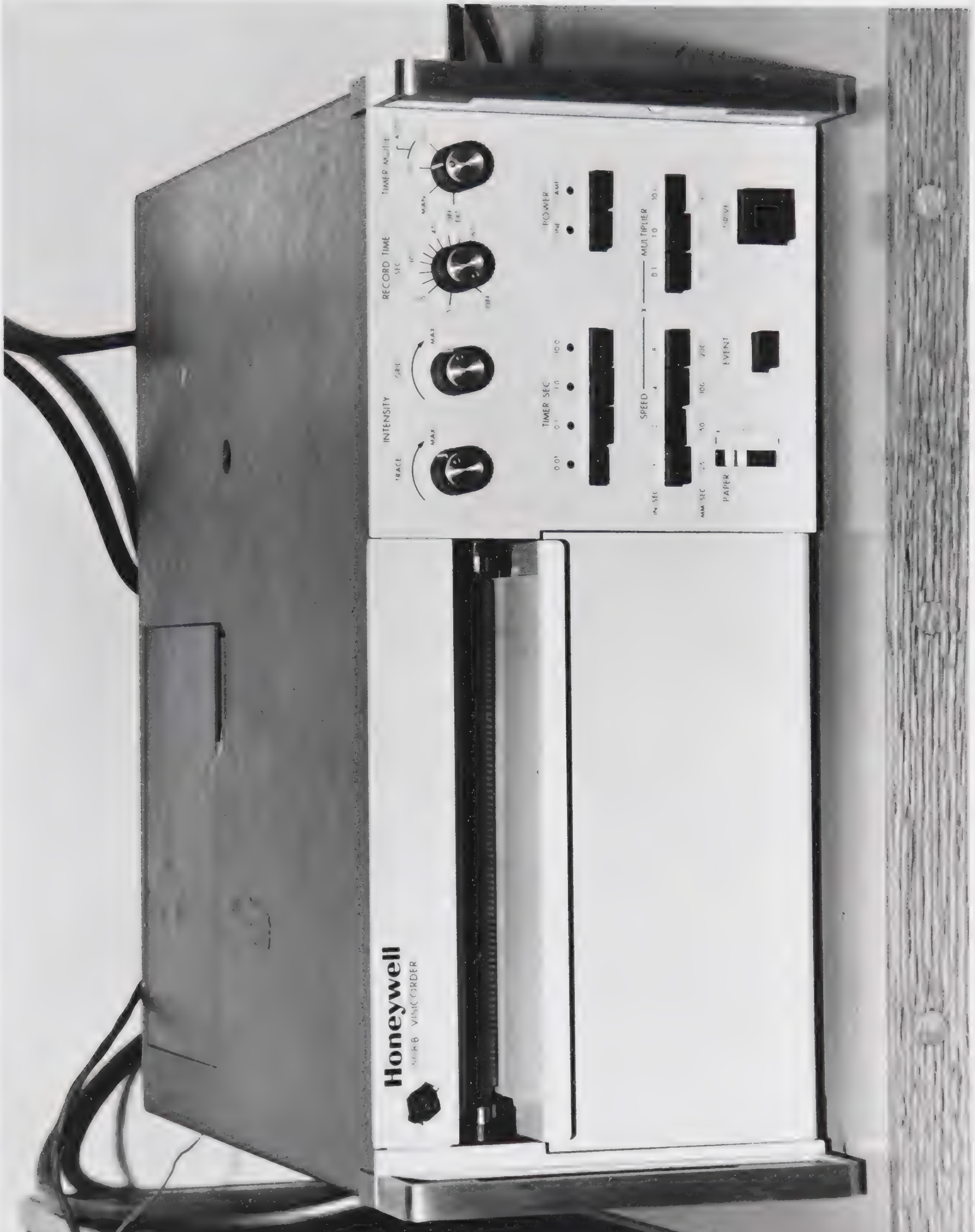


Fig. 8. Recorder

turned off and the driving speed for recordings was set at 0.5 centimeter per second with spacing of the time lines of 0.5 centimeter.

7. Electrical stimulator

A. Description

The model used was a SD-9 square wave stimulator from Grass Instruments (Figure 9). It offered built-in stimulus isolation.

B. Operation

The search for the tibial nerve in the popliteal fossa was done using a frequency of stimulation of 1 pps (pulse per second). Recording of both H- and M- responses were done using a frequency of 0.2 pps (Delwaide, 1971; Hugon, 1973).

The duration of the stimulating square wave was set at 1 millisecond for both H- and M-responses. The 50 microseconds duration of the square wave recommended by Veale (1973) for the M-response could not be used because too near maximal intensity of stimulation (100 volts) had to be performed, thus evoking the eventuality of a submaximal M-response with maximal possible intensity of stimulation in some subjects.

Voltage applied through the stimulating cathode was initially set at 10 volts and increased progressively for maximum H-responses firstly and M-responses secondly.

Synchronization of the cathode ray oscilloscope sweep with the stimulation pulse was accomplished by connecting leads from the SYNC PULSE OUT and GROUND terminals of the stimulator to the EXT TRIGGER INPUT and GROUND terminals respectively of the oscilloscope.

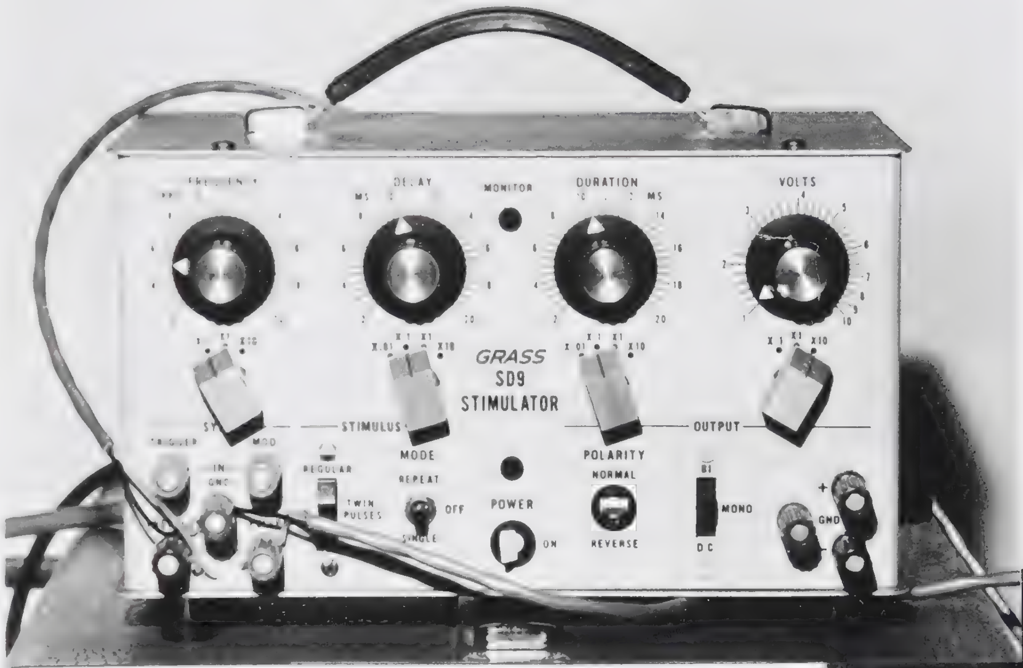


Fig. 9. Electrical stimulator.

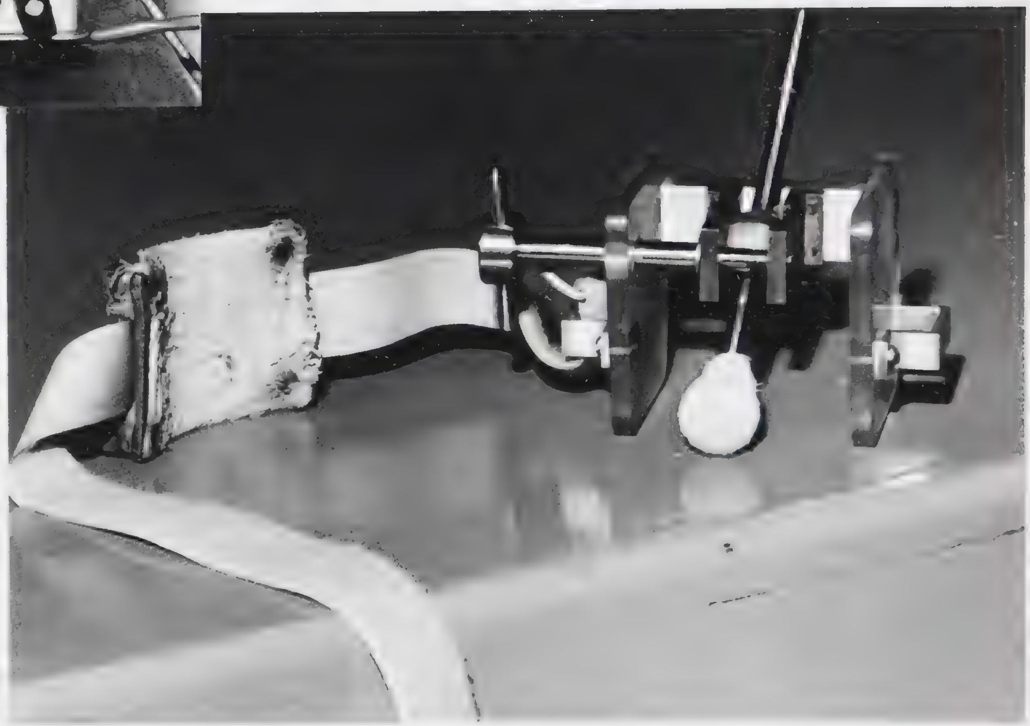


Fig. 10. Stimulating electrodes

Synchronization of the oscillographic paper recording with the stimulating pulse was done by the relay circuit (Figure 7) in between the stimulator and the recorder. Connecting leads were inserted into the SYNC PREPULSE OUT and GROUND terminals of the stimulator and into the EXT DRIVE and GROUND terminals of the recorder. The DELAY dial was set at 100 milliseconds, meaning that the recorder was being driven 100 milliseconds before the stimulating pulse came out. This operation was done to let the recorder to attain its driving speed before any recording were made.

8. Stimulating electrodes

Monopolar stimulation in the popliteal fossa was used to obtain H- and M-responses of the soleus muscle by excitation of the posterior tibial nerve. Simon's electrodes (1962) slightly modified by Delwaide (personal communication) were used (Figure 10).

9. Oscilloscope

The monitoring oscilloscope used was the two-channel TYPE 544 oscilloscope from Tektronix which had an external triggering capability (Figure 11). Speed of sweep was set at 10 milliseconds per centimeter. Output from the biomedical amplifier was monitored on the first channel (upper) and output from the bridge amplifier was monitored on the second (lower). Both gains were so adjusted that full amplitude on the oscilloscope corresponded with full amplitude on the oscillographic recorder.

Fig. 11. Oscilloscope

PROTOCOL

Three studies were conducted in the same conditions of training and/or testing. The first one used twenty-two male physical education students, from 19 to 26 years of age, randomly divided into two groups: a control group and an experimental group of eleven subjects each. The latter was subjected to a program of strength training of the right calf muscles. In the second study, eight sedentary male subjects, from 17 to 34 years of age, were also randomly divided into two groups: a control group of four subjects and an experimental group of four subjects who went through the same training program as in the first study. For the third study, four male weight lifters, from 20 to 22 years of age, who could clean and jerk on the average 1.77 pounds per pound of body weight (Appendix C) were tested for presence or absence of supraspinal reflexes following their muscle twitches.

1. Muscle strength training

Only one leg was subjected to training and it was decided that the right leg would be used. In the first two studies (study I: physical education students and study II: sedentary subjects) muscle strength training lasted five weeks (Saturdays and Sundays excluded). All of the subjects in the experimental group of both studies started their training on a certain day of the initial week and ended the training on the same day, five weeks later. The subjects of the control group in both studies were tested for muscle strength during this same period but at an interval of 35 days. The training program consisted of five daily maximum plantar flexions (static) of six second duration each and each separated by a 54 second rest, five days per week for five weeks.

After putting on the boot, the subjects knelt down before the plinth onto the biomechanical table and leaned onto the plinth taking care that their thighs were against the slope of the plinth (Figure 3). The boot was then slid onto the foot pedal till the malleolus was in line with the axis of rotation of the foot pedal and was held tight in place with the penetrating rod (Figure 5).

2. Muscle twitch testing

Once a week, before the training session, the contractile properties of the soleus muscle being trained were evaluated.

Adopting the same position as for training, the subjects were asked to remain completely relaxed until the testing was completed.

Simon's electrodes (1962) were firstly soaked in a saline solution (0.9% NaCl). The anode was inserted between the slope of the plinth and the thigh and positioned just above the patella against the skin overlying the tendon of the quadriceps femoris. The mobile cathode was positioned in the popliteal fossa and both the electrodes were held together with a Velcro strap running around the thigh just above the knee joint (Figures 3 and 5).

The area of the skin chosen to receive the pick-up and ground electrodes was rubbed with alcohol after the hair of the leg had been removed with a razor blade. The surface electrodes were filled with conductive paste and adhesive collars were used to stick them on the skin. The pick-up electrodes were positioned in the axis of the Achilles tendon at mid-distance from the head of the fibula and the tip of its malleolus (Ginet, 1975) in order to record only from the soleus (Hugon, 1973). The ground electrode was positioned on the same line but in-between the stimulating cathode and the pick-up electrodes (Figure 5). At the first testing session, the position of

the plastic plate holding these electrodes was marked with a felt pen and the subjects were asked not to rub it off for the five weeks of the experimentation.

Stimulation and recording electrodes were then connected to their respective terminals on the stimulator and biomedical amplifier respectively.

Testing started by the search for the posterior tibial nerve with the mobile cathode bringing a one-millisecond square wave of ten volts at a frequency of one Hertz (Delwaide, 1971; Hugon, 1973). The cathode was moved in the popliteal fossa until the maximal electromyographic response as given by the soleus and shown on the oscilloscope was obtained with the minimal intensity of stimulation. The mobile cathode was then rendered fixed by turning clockwise an especially designed key on the frame holding the cathode (Figure 10). The H-wave was monitored with a latency to stimulation of 30 to 40 milliseconds. Five recordings of the muscle twitch with its electromyographic signal (the H-wave) were taken at a frequency of one each five seconds.

Thereafter, the intensity of nerve stimulation was increased until another electromyographic response of the soleus (the M-wave) of shorter latency to stimulation, i.e. 5 to 10 milliseconds, became maximal with supramaximal intensity of stimulation. In the mean time, the H-wave diminished progressively because of antidromic conduction on the motor fibres being recruited (Ginet, 1975). Five recordings of the muscle twitch with its electromyographic signal (the M-wave) were taken at a frequency of one each five seconds.

The subjects of the control group in both training studies were evaluated following the same procedure before and after the training program of the experimental group.

The muscle twitches were always recorded before the subjects of both groups in both studies exerted their maximal static plantar flexions.

3. Statistical Analysis

A. Muscle strength training

A one-way analysis of covariance was used to test the means of the maximal developed tension of both the control and experimental groups before and after the training program (Clarke, 1972).

B. Muscle twitch testing

Since the H-response could not be recorded in all of the subjects of both groups, Student t was used to test the means of both groups at both stages (pre and post) (Dixon, 1969). This was done for the contraction time, the half-relaxation time and the twitch tension of the H-response.

A two-way analysis of variance with repeated measures on one factor was used to test the contractile properties of the M-response of both groups at both stages. The contraction time, the half-relaxation time and the twitch tension of the M-response were thus tested for significance (Winer, 1962).

CHAPTER III

RESULTS

1. Muscle strength

Maximal strength of the right calf muscles was defined as the peak developed tension in each of the five trials of six second duration each of a session. The five values were averaged to give maximum voluntary static plantar flexion. Reported means (Tables 2 and 3) were not corrected for the length of the foot pedal at the end of which the force transducer was hooked. True tensions would have therefore been around twice the reported values since the ball of the foot was located at approximately six inches from the malleolus. Since the boot was inserted to the same level for each subject in all of the testing sessions, it was not felt necessary to correct the tension values for the lever arm in the analysis of covariance.

A. Study I: physical education students

The analysis of covariance (Table 2) revealed that the physical education students ($n = 11$) did not gain any significant muscle strength in their right calf muscles ($P > .05$).

B. Study II: sedentary subjects

The mean muscle strength increment in the sedentary subjects ($n = 4$) was 28% after the five weeks of the training program (Table 3) which was

TABLE 2. Mean, standard deviation and F for muscle strength training (Study I, physical education students)

Maximum voluntary static plantar flexion

Group	Control (n = 11)		Experimental (n = 11)	
Stage	Pre (lbs)	Post (lbs)	Pre (lbs)	Post (lbs)
Mean	126.77	128.22	148.31	149.89
Standard deviation	22.28	21.04	26.58	31.18

Analysis of covariance

Source of Variation	SS	df	MS	F
Between subjects	215.73	1	215.73	0.842
Within subjects	8486.57	19	446.66	

TABLE 3. Mean, standard deviation and F for muscle strength training (Study II, sedentary subjects)

Maximum voluntary static plantar flexion

Group	Control (n = 4)		Experimental (n = 4)	
Stage	Pre (lbs)	Post (lbs)	Pre (lbs)	Post (lbs)
Mean	94.95	106.90	95.42	122.00
Standard deviation	15.25	10.57	15.44	4.27

Analysis of covariance

Source of variation	SS	df	MS	F
Between subjects	446.56	1	446.56	9.320*
Within subjects	239.57	5	47.91	

* $P < .05$

identical to the one used in study I. The gain was significant ($P < .05$).

2. H-response

A. Study I: physical education students

A two-way analysis of variance with repeated measures on one factor (which requires equal n's) could not be performed on the parameters of the H-response (contraction time, half-relaxation time and twitch tension) because these contractile properties were not obtained for all of the subjects. The reasons are: in some subjects, a pure H-response, i.e. not contamined with preceding M-response, was not apparent and therefore a summation of two twitches (M and H) made the calculation of the contraction time, the half-relaxation time and the twitch tension of the H-response impossible; in others, a M-response hidden in the background noise of the electromyographic signal (monitor and recorder) brought a similar summation of twitches; finally in others, even though the H-response was pure, its mechanical reaction (the muscle twitch) was too small to permit an accurate estimation of the maximum point on the twitch curve where the contraction stopped and the relaxation started.

Multiple Student t-tests were therefore performed to test the means of both groups at both stages of the contraction time (Table 4), the half-relaxation time (Table 5) and the twitch tension (Table 6) of the H-response.

B. Study II: sedentary subjects

In three out of four control subjects in this study, a pure H-response could not be obtained, probably because of a similar fibre diameter of the primary spindle afferents and of the low-threshold alpha-motor axons in these subjects (Veale, 1973). No statistical analysis were therefore per-

TABLE 4. Mean, standard deviation and t for H contraction time (Study I, physical education students)

H-response

muscle twitch contraction time

Group	Control		Experimental	
Stage	Pre (m.sec)	Post (m.sec)	Pre (m.sec)	Post (m.sec)
Mean	111.64	102.27	101.94	96.22
Standard deviation	6.18	2.32	11.42	13.88

Student t

Control		Experimental	
Pre (n = 5)	Post (n = 3)	Pre (n = 9)	Post (n = 7)

2.458*

0.903

1.743

0.724

*P < .05

TABLE 5. Mean, standard deviation and t for H half-relaxation time (Study I, physical education students)

H-response muscle twitch half-relaxation time				
Group	Control		Experimental	
Stage	Pre (m.sec)	Post (m.sec)	Pre (m.sec)	Post (m.sec)
Mean	62.88	55.07	68.58	64.74
Standard deviation	13.93	2.80	10.52	10.26

Student t

Control		Experimental	
Pre (n = 5)	Post (n = 3)	Pre (n = 9)	Post (n = 7)

0.930

0.730

-0.868

-1.558

TABLE 6. Mean, standard deviation and t for H-twitch tension
(Study I, physical education students)

H-response				
Group	Control		Experimental	
Stage	Pre (lbs)	Post (lbs)	Pre (lbs)	Post (lbs)
Mean	8.77	9.43	10.93	8.20
Standard deviation	3.58	2.79	4.57	2.65

Student t

Control		Experimental	
Pre (n = 5)	Post (n = 3)	Pre (n = 9)	Post (n = 7)

-0.272

1.398

-0.907

0.663

formed on this response in this study.

3. M-response

A. Study I: physical education students

In the eighth subject of the control group (Appendix D), the M-response before the training program was not evaluated because the M-wave was followed by another wave of short latency (probably an F-wave, Milner-Brown et al., 1975) causing again a summation of twitches. For this subject, the mean values of his group were allotted to him for his contraction time, half-relaxation time and twitch tension.

In the fifth subject of the control group, after the training program (Appendix D), tonic firing supervened during the relaxation phase of his muscle twitches. The mean half-relaxation time of his group at that stage was given to him.

Finally, in the fourth subject of the experimental group (Appendix D), the first twitch of the M-response was not properly recorded during the post-training evaluation and was therefore discarded. The mean values of his contraction time, half-relaxation time and twitch tension were calculated from his four subsequent muscle twitches.

A two-way analysis of variance with repeated measures on one factor was performed to test the means of the contraction time (Table 7), the half-relaxation time (Table 9) and the twitch tension (Table 11) for statistical significance. The only significant difference encountered was in twitch tension, but because the interaction was not significant the difference cannot be accounted for by the training program.

B. Study II: sedentary subjects

During muscle twitches subsequent to the initial one, tonic firing of motor units prevented relaxation of the soleus muscle of the second subject of the post-training control group (Appendix E). The contraction time, the half-relaxation time and the twitch tension of the first twitch were taken then to calculate the mean of the group.

The relaxation tension during the first twitch of the second subject of the pre-training experimental group went below baseline levels (undershoot). This probably meant that the subject was not completely relaxed (Stein, personal communication). The other four values were taken to calculate the mean of his trials.

A two-way analysis of variance with repeated measures on one factor of the parameters of the M-response (Tables 8, 10 and 12) revealed a significant difference ($P < .01$) with training in the half-relaxation time only which diminished to 82% of the pre-training value.

4. Supraspinal reflexes

In some of the subjects of the three studies (physical education students, sedentary subjects, weight lifters), an electromyographic response (tonic or phasic) was recorded just after the relaxation phase of the muscle twitch of the M-response, i.e. with a latency in the neighbourhood of 225 milliseconds following nerve stimulation. Milner-Brown et al. (1975) attributed these waves to supraspinal reflexes following nerve stimulation.

A. Study I: physical education students

Supraspinal reflexes were recorded in four subjects of the control group before and after the training program, in five subjects of the

experimental group before the training program, and after the training program in nine of the subjects of the latter group.

A "phi" coefficient (Clarke, 1972) was calculated to show whether the presence of the supraspinal reflexes in both groups at both stages was significant (Table 13). Transferred to a chi-square distribution, this coefficient was shown not to be significant ($P > .05$).

B. Study II: sedentary subjects

None of the control subjects showed signs of supraspinal reflexes following nerve stimulation before and after a five week experimental period. Only one experimental subject showed these supraspinal reflexes following muscle twitches in the post training recordings but these were also present in the pre-training recordings.

C. Study III: weight lifters

Only one of the four weight lifters showed the supraspinal reflexes in the recording of soleus muscle twitches.

TABLE 7. Mean, standard deviation and F for muscle twitch (M) contraction time (Study I, physical education students)

M response

muscle twitch contraction time

Group	Control (n = 11)		Experimental (n = 11)	
Stage	Pre (msec)	Post (msec)	Pre (msec)	Post (msec)
Mean	96.56	92.38	93.33	93.84
Standard deviation	14.76	18.50	11.12	8.97

Analysis of variance

Source of variation	SS	df	MS	F
Between subjects	6855.37			
A (Group)	8.61	1	8.61	0.025
Subjects within groups	6846.76	20	342.34	
Within subjects	891.19			
B (Stage)	36.84	1	36.84	0.928
AB	60.65	1	60.65	1.528
B X Subjects within groups	793.70	20	39.68	

TABLE 8. Mean, standard deviation and F for muscle twitch (M) contraction time (Study II, sedentary subjects)

M-response muscle twitch contraction time

Group	Control (n = 4)		Experimental (n = 4)	
Stage	Pre (msec)	Post (msec)	Pre (msec)	Post (msec)
Mean	102.15	102.50	87.70	96.65
Standard deviation	18.22	14.25	21.39	12.12

Analysis of variance

Source of variation	SS	df	MS	F
Between subjects	3417.47	7		
A (Group)	400.00	1	400.00	0.795
Subjects within groups	3017.47	6	502.91	
Within subjects	572.12	8		
B (Stage)	92.16	1	92.16	1.379
AB	69.21	1	79.21	1.185
B X subjects within groups	400.75	6	66.79	

TABLE 9. Mean, standard deviation and F for muscle twitch (M) half-relaxation time (Study I, physical education students)

M response

muscle twitch half-relaxation time

Group	Control (n = 11)		Experimental (n = 11)	
Stage	Pre (msec)	Post (msec)	Pre (msec)	Post (msec)
Mean	83.48	80.82	81.05	73.06
Standard deviation	11.56	12.71	9.69	10.56

Analysis of variance

Source of variation	SS	df	MS	F
Between subjects	3799.07			
A (group)	285.09	1	285.09	1.622
Subjects within group	3513.98	20	175.70	
Within subjects	1885.04			
B (stage)	311.96	1	311.96	4.173
AB	78.15	1	78.15	1.045
B X subjects within groups	1494.93	20	74.75	

TABLE 10. Mean, standard deviation and F for muscle twitch (M) half-relaxation time (Study II, sedentary subjects)

M-response muscle twitch half-relaxation time

Group	Control (n = 4)		Experimental (n = 4)	
Stage	Pre (msec)	Post (msec)	Pre (msec)	Post (msec)
Mean	80.85	78.00	91.92	75.5
Standard deviation	14.52	16.41	11.99	12.09

Analysis of variance

Source of variation	SS	df	MS	F
<u>Between subjects</u>	2305.47	7		
A (Group)	73.53	1	73.53	0.198
Subjects within groups	2231.94	6	371.99	
<u>Within subjects</u>	634.09	8		
B (Stage)	371.53	1	371.53	28.49**
AB	184.28	1	184.28	14.13**
B X subjects within groups	78.28	6	13.04	

**P < .01

TABLE 11. Mean, standard deviation and F for muscle twitch (M) tension (Study I, physical education students)

M response muscle twitch tension

Group	Control		Experimental	
Stage	Pre (lbs)	Post (lbs)	Pre (lbs)	Post (lbs)
Mean	15.72	13.41	14.92	14.04
Standard deviation	3.83	3.38	4.95	5.49

Analysis of variance

Source of variation	SS	df	MS	F
Between subjects	721.97			
A (Group)	0.08	1	8.51	0.002
Subjects within groups	721.89	20	36.09	
Within subjects	118.41			
B (Stage)	28.05	1	28.05	6.621*
A B	5.61	1	5.61	1.324
B X Subjects within groups	84.75	20	4.24	

TABLE 12. Mean, standard deviation and F for muscle twitch (M) tension (Study II, sedentary subjects)

M-response muscle twitch tension

Group	Control (n = 4)		Experimental (n = 4)	
Stage	Pre (lbs)	Post (lbs)	Pre (lbs)	Post (lbs)
Mean	10.02	11.10	9.45	11.26
Standard deviation	4.60	4.71	0.54	1.48

Analysis of variance

Source of variation	SS	df	MS	F
<u>Between subjects</u>	127.06			
A (Group)	0.16	1	0.16	0.007
Subjects within groups	126.90	6	21.15	
<u>Within subjects</u>	19.43	8		
B (Stage)	8.35	1	8.35	4.758
A B	0.55	1	0.55	0.312
B X Subjects within groups	10.53	6	1.75	

TABLE 13. Phi-coefficient and chi-square calculated from the presence of supraspinal reflexes

	Pre	Post	
Con	B = 4	A = 4	P = A+B = 8
Exp	D = 5	C = 9	Q = C+D = 14
	P' = B+D = 9	Q' = A+C = 13	

N = P+Q = P' +Q' = 22

$$\phi = \frac{AD - BC}{\sqrt{PQP'Q'}}$$

$$= \frac{(4 \times 5) - (4 \times 9)}{\sqrt{8 \times 14 \times 9 \times 13}}$$

$$= -\ 0.14$$

$$X^2 = N\phi^2$$

$$= 22 \times (-0.14)^2$$

$$= 0.43$$

CHAPTER IV

DISCUSSION

1. Muscle strength

Mean maximal values for plantar flexion of all groups in studies I and II were below the mean maximal value of five subjects reported by Haxton (1944). From his data on the absolute muscle force in the ankle flexors in man, the estimated tension at the ball of the foot was in the order of 360 pounds. In the present studies, tension averaged from 200 to 300 pounds for all groups. The difference can perhaps be accounted for by the amount of leg extension during the tension measurements. His subjects had their right leg fully extended whereas the subjects in the present studies had their right knee flexed at an angle of 120 degrees, thus removing some of the action of the gastrocnemius muscles.

The training program of the experimental group in the first study was based on Muller's observations (Figures 1 and 2). He stated that the increase in strength, up to a limiting value, was similar for all persons, muscles, ages and sexes. The subjects of this experimental group showed no significant gain in strength over the five-week training program. Regardless of the lack of motivation in these physical education students, one must conclude that these subjects did not train hard enough in order to increase their maximal voluntary tension (overload principle) because the same training program was given to a sedentary group (Study II) which showed significant

increase (28%) in muscle strength.

2. H-response

This response as previously explained was only analyzed in the first study with physical education students. In both the control and the experimental groups, the mean contraction time decreased from the pre-stage to the post-stage (Table 4). However, the difference was only statistically significant in the control groups. Buchthal (1970 b) reported a mean contraction time for the H-reflex of a group of four males and two females aged 18 to 20 years, of 98 $\pm$ .8 milliseconds which is consistent with the present reported values (Table 4).

The decrease in contraction time of the H-response of the subjects in the control group was significant probably for the following reason:. the probability of getting a significant difference when performing t-tests increases with the number of tests performed. In the present experiment, the statistical difference (Table 4) was significant just beyond the alpha level ($P = .05$).

The findings that the muscle twitch tension of the H-response were not modified by the training program support work of Milner-Brown et al. (1975). They found no difference in the H-response: M-response ratio (both EMG amplitudes of the thenar muscles obtained by stimulation of the median nerve) before and after six weeks of isometric training of thumb and index finger adduction of the non-dominant hand. Ginet et al. (1975) studied this ratio (H max/M max) and the absolute value of H max on the soleus muscle of 42 sedentary normal subjects and 57 high level athletes and found that the state of training was response for the observed significant differences in this ratio and the absolute value between the groups. However, most of their

athletes were involved in aerobic type of sport such as cycling, soccer, basket-ball, rowing and track and field.

3. M-response

Mean contraction time of all groups in both training studies lay between 92 and 103 milliseconds (Tables 7 and 8) which are some 25 per cent higher than the 74 msec mean reported by Buchthal and Schmalbruch (1970 b). The difference can be accounted for by their methods of recording: a strain-guaged needle was implanted into the Achilles tendon of the subjects. The non-significant change of the contraction time in the experimental group of both training studies is in accordance with the study of Exner et al. (1973) who subjected male rats to a 35 day isometric training program. One of the bases for the differentiation of skeletal muscle fiber types, contractile speed (Gollnick, 1974) is directly related to myosin ATPase activity (Buchthal, 1970 a; Hanson, 1974). Based on this premise the results of the present studies support those of Syrovy et al. (1972) who showed no modification in myosin ATPase activity of the soleus muscle of older rats after a nine week swimming program.

Mean half-relaxation time decreased in both training studies from 81.0 msec to 73.6 msec in study I ($P > .05$) and from 91.0 msec to 75.5 msec in study II ($P < .01$). It seems therefore that the higher the level of training, the lower is the half-relaxation time (weight lifters had a mean half-relaxation time of 66.7 msec) and that a specific training program will probably affect less subjects at higher state of training (the overload principle).

Muscle twitch tension was not affected by the training program in both training studies (Tables 11 and 12). Since the physical education

students did not increase their maximal voluntary static strength and the sedentary subjects did, one must conclude that the increase in gross muscle strength does not parallel an increase in muscle twitch tension. An increase in frequency of discharge of motor units may account for the increase in maximal voluntary contraction.

4. State of training

From the data recorded in the four weight lifters, long term training does not seem to modify the contractile properties of the soleus muscle more than short term training does on physical education students and sedentary subjects. The mean contraction time, half-relaxation time and twitch tension were 107 msec, 66.7 msec and 12.3 lbs respectively. Therefore, it seems the contraction time (Tables 7 and 8) is not related to the state of training and this is in accord with the observations of Buchthal and Schmalbruch (1970 b). The twitch tension (Tables 11 and 12) is apparently not related to the state of training since the maximal static plantar flexion tension of the weight lifters was low (mean of 140 lbs). The ratio of twitch tension to maximal voluntary tension also does not seem to be related to the state of training. However, the half-relaxation time (Tables 9 and 10) tended to be shorter the higher the level of training; this may indicate a faster uptake of calcium by the sarcoplasmic reticulum as the state of training is increased.

5. Supraspinal reflexes

The tonic or phasic firing of soleus motor units seen in subjects following the relaxation phase of the twitch was assumed to be supraspinal reflexes responsible for synchronization of motor units firing to produce

stronger contraction during steady, voluntary contractions (Milner-Brown et al. 1975). However, these EMG waves which they named V_3 and V_2 (V_1 being equal to H) had latent periods following electrical stimulation of the median nerve at the wrist equal to 56 and 83 milliseconds respectively. Since median nerve conduction velocity and ulnar nerve conduction velocity are essentially the same, i.e. 58 meters per second (Smorto, 1972) and since contraction time is highly related to nerve conduction velocity (Bagust, 1974), one can assume that the contraction time the the thenar muscles is similar to that of the first dorsal interosseus muscle which is innervated by the ulnar nerve. Milner-Brown et al. (1973) who studied the contractile properties of the first dorsal interosseus muscle reported a mean contraction time of 55 milliseconds and a mean half-relaxation time of 42 milliseconds. This would mean then that their V_2 and V_3 waves (supraspinal reflexes) occurred at the end of the contraction (or at the start of the relaxation) and midway into relaxation of the muscle twitch respectively. As mentioned previously, the waves seen in many of the physical education students (Table 13) and in one of the sedentary subjects of these studies occurred after the relaxation of the muscle twitch. One might question then the association between the waves seen in the present studies and the V_2 and V_3 waves observed by Milner-Brown et al. (1975). The electrical stimulation in their study was delivered to a nerve leading to a muscle being voluntarily contracted whereas in the present studies, the subjects were fully relaxed. To test whether the association was legitimate, a subject (M.L.) of study (was asked to exert steady, voluntary contractions of the calf muscles at different levels of his maximum strength. At rest, phasic firing of the soleus motor units occurred after the relaxation phase of the muscle twitch; from 25% to 60% of his maximal muscle strength, firing of the soleus motor units occurred during the relaxation phase and at 75%

to 90% of his maximal strength, firing of the soleus motor units after electrical stimulation was no longer phasic, but tonic, starting at the end of the contraction phase of the muscle twitch. In other words, the firing of the soleus motor units following electrical stimulation (with the exception of the M-response) happened sooner with stronger muscle contractions. The mechanism might be explained by an increased feedback processing of proprioceptive signals due to irradiation from the pyramidal tract neurons to sub-cortical regions. These waves were shown to be greatly potentiated following a standard submaximal exercise on the bicycle ergometer (unpublished observations). For this type of exercise, hyperpnea and tachycardia occur because of an increased activity in the medulla oblongata which contains the Goll and Burdach nuclei, sites of some relayed proprioceptive signals (lemniscal route). The medulla oblongata is therefore thought to be related in a way to the supraspinal waves observed in this research. It seems likely then that the V_2 and V_3 waves observed by Milner-Brown et al. (1975) can be associated to the waves observed in the present studies.

The presence of these waves was not shown to be significantly affected by a muscle strength training program (Table 13) though the physical education students did not gain any significant muscle strength after five weeks of training (Table 2). The sedentary subjects in study II did increase their muscle strength with the same training program (Table 3) and these waves were present in only one case after training, however, in this case they were observed before the training program began.

To determine whether a short-term training program was the reason for the non-significant presence of these waves, four weight lifters who had been training on the average for three years (Appendix C) were tested in the same conditions as in the first two studies. In the case of

only one weight lifter did these waves become apparent. Therefore, the present report does not support the results of Milner-Brown et al. (1975) in explaining the increase in muscle strength through synchrony of recruitment via a supraspinal reflex pathway. However, the earlier late waves with stronger contractions in one subject seen may not be of supraspinal origin but may indicate the increase firing of higher threshold motor units which were recruited during stronger muscle contractions. On the other hand, this latter explanation would not account for the presence of late waves in resting subjects being electrically stimulated.

CONCLUSION

Three studies were conducted to relate the contractile properties to muscle strength training. The first and second studies included physical education students and sedentary subjects respectively. Both groups trained their leg extensors doing five maximal static plantar flexions flexions of their right foot for a period of five weeks. The third study included weight lifters who were considered to have trained on a long-term basis. The contractile properties of the soleus muscle were evaluated using monopolar stimulation of the tibial nerve innervating the soleus muscle.

The training program only succeeded in increasing the muscle strength of the sedentary subjects. The trainability of the physical education students must have been less, considering the specific muscle strength training program. Thus, the contractile properties of the soleus muscle of the physical education students were not significantly modified by the training program.

On the other hand, the sedentary subjects increased their muscle strength following this same training program. Only the half-relaxation time in this group was significantly lowered. The contractile properties of the soleus muscle of the weight lifters showed that the half-relaxation time appeared to be related to the level of training.

Hypothesized supraspinal waves following the elicited muscle twitches were recorded in many of the physical education students, in one

of the sedentary subjects and in one of the weight lifters. These waves could not be related to the muscle strength gain following the training program.

Out of the three factors responsible for muscle tension increment during voluntary contraction, i.e. recruitment of motor units, their frequency of firing and the synchrony of recruitment. The frequency of firing may have increased as a result of training of the sedentary subjects.

BIBLIOGRAPHY

Astrand, P.O. and K. Rodahl. Textbook of Work Physiology. McGraw-Hill, New York, 1970.

Bagby, G. J., W.L. Sembrowich and P.D. Gollnick. Myosin ATPase and Fiber composition from trained and untrained rat skeletal muscle Am. J. Physiol. 223: 1415-1417, 1972.

Bagust, J. Relationships between motor nerve conduction velocities and motor unit contraction characteristics in a slow twitch muscle of the cat. J. Physiol. (London) 238: 269-278, 1974.

Barnard, R.J., V.R. Edgerton and J. B. Peter. Effect of exercise on skeletal muscle I. Biomechanical and histochemical properties. J. Appl. Physiol. 28: 762-766, 1970.

Brooke, M. and K. Kaiser. Muscle fiber types: How many and what kind? Arch. Neurol. 23: 369-379, 1970.

Buchthal, F. and H. Schmalbruch. Contraction times and fibre types in intact human muscle. Acta Physiol. Scand. 79: 435-452, 1970 a.

Buchthal, F. and H. Schmalbruch. Contraction times of twitches evoked by H-reflexes. Acta Physiol. Scand. 80: 378-382, 1970 b.

Burke, R.E. On the central nervous system control of fast and slow twitch motor units. New Developments in Electromyography and clinical Neurophysiology, edited by J.E. Desmedt, Vol. 3, pp. 69-94 (Karger, Basel, 1973).

Burke, R.E. and V.R. Edgerton. Motor unit properties and selective involvement in movement. Exercise and Sport Science Reviews. Academic Press, New York, Vol. 3: 31-81, 1975.

Clarke, H.H. and D.H. Clarke. Advanced Statistics with Applications to Physical Education. Prentice Hall Inc., Englewood Cliffs, 1972.

Close, R.I. Dynamic properties of mammalian skeletal muscles. Physiol. Rev. 52: 129-197, 1972.

de Jong, R. and F.G. Freund. Relation between electromyogram and isometric twitch tension in human muscle. Arch Phys Med Rehab 48: 539-542, 1967.

Delwaide, P.J. Etudes expérimentales de l'hyperréflexi tendineuse en clinique neurologique. Arscia. Bruxelles. 1970.

Dixon, W.J. and F.J. Massey. Introduction to Statistical Analysis. McGraw-Hill, New York, 1969.

Dubowitz, V. and A. Pearse. Reciprocal relationship of phosphorylase and oxidative enzymes in skeletal muscle. Nature (London) 185: 701-702, 1960.

Edington, D.W. and V.R. Edgerton. The Biology of Physical Activity. Houghton Mifflin Company, Boston, 1976.

Edström, L. and B. Nyström. Histochemical types and sizes of fibers in normal human muscles. Acta Neurol Scandinav. 45: 257-269, 1969.

Engel, W. The essentially of histo- and cytochemical studies of skeletal muscle in the investigation of neuromuscular disease. Neurol. 12: 778-784, 1962

Exner, G.U., H. W. Staudte and D. Pette. Isometric training of rats - effects upon fast and slow muscle and modification by an anabolic hormone (Nandrolone decanoate) I. Female rats. Pflügers Arch. 345: 1-14, 1973.

Exner, G.U., H.W. Staudte and D. Pette. Isometric training of rats - effects upon fast and slow muscle and modification by an anabolic hormone (Nandrolone decanoate) II. Male rats. Pflügers Arch. 345: 15-22, 1973.

Fenichel, G.M. and W.K. Engel. Histochemistry of muscle in infantile spinal muscular atrophy, Neurology 13: 1059-1066, 1963.

Fitts, R., D. Campion, F. Nagle and R. Cassens. Contractile properties of skeletal muscle from trained miniature pig. Pflügers Arch. 343: 133-141, 1973

Ginet, J., Guiheneuc, P., Prévot, M. et F. Vecchierini-Blineau. Etude comparative du recrutement de la réponse réflexe monosynaptique du soléaire (réflexe H) chez des sujets non entraînés et chez des sportifs. Médecine du Sport. 49: 55-64, 1975.

Gollnick, P., K. Piehl and B. Saltin. Selective glycogen depletion in skeletal muscle fibers of man following sustained contractions. J. Physiol. (London) 241: 59-68, 1974 a.

Gollnick, P.D.B. Sijödin, J. Karlsson, E. Jansson and B. Saltin. Human soleus muscle: a comparison of fiber composition and enzyme activities with other leg muscle. Pflügers Arch. 348: 247-255, 1974 b.

Gordon, A.M., A.F. Huxley and F.J. Julian. The variation in isometric tension with sarcomere length in vertebrate muscle fibers. J. Physiol. (London) 184: 170-192, 1966.

Gordon, E.E. Anatomical and biochemical adaptations of muscle to different exercises. JAMA 201: 755-758, 1967.

Guiheneuc, P. et J. Ginet. Le réflexe de Hoffmann. Signification de l'intervalle entre les réponses H et M et intérêt de sa mesure. C.R. Soc. Biol. 165: 1763-1766, 1971.

Granit, R. The functional role of the muscle spindles - Facts and hypotheses. Brain 98: 531-556, 1975.

Hannertz, J. Discharge properties of motor units in relation to recruitment order in voluntary contraction. Acta Physiol. Scand. 91: 374-384, 1974.

Hanson, J. Effects of repetitive stimulation on membrane potentials and twitch in human and rat intercostal muscle fibres. Acta Physiol. Scand. 92: 238-248, 1974.

Haxton, H.A. Absolute muscle force in the ankle flexors of man. J. Physiol. (London) 103: 267-273, 1944.

Hénane, R. and J. A. Macarez. Effets de l'exercice physique sur la réflectivité spinale chez l'homme. Int. Z. angew. Physiol. 30: 315-334, 1972

Henneman, E. and C.B. Olson. Relations between structure and function in the design of skeletal muscles. J. Neurophysiol. 28: 599-620, 1965.

Hettinger, T. Physiology of Strength. C.C. Thomas, Springfield, 1961.

Hettinger, T. and E. A. Muller. Muskelleistung und training. Arbeits physiologie 15: 111-126, 1953.

Hoffmann, P. Uber die beziehungen der Sehnen reflexe zur wilkurlichen bewegung und zum tonus. Z. Biol. 68: 351-370, 1918.

Hugon, M. Methodology of the Hoffmann reflex in man. New Developments in Electromyographic and Clinical Neurophysiology, edited by J.E. Desmedt, Vol. 3, pp. 277-293 (Karger, Basel, 1973).

Ikai, M. and A. H. Steinhaus. Some factors modifying the expression of human strength. J. Appl. Physiol. 16: 157-163, 1961.

Jennekens, F.G.I., B. E. Tomlinson and J.N. Walton. Data on the distribution of fibre types in five human limb muscles. J. Neurol. Sci. 14: 245-257, 1971.

Kirsten, G. Der Einfluss isometrischen Trainings auf die Entwicklung der Muskelkraft Jugendlicher. Int. Z. angew Physiol. 19: 378-402.

Milner-Brown, H.S., R.B. Stein and R.G. Lee. Synchronization of human motor units: possible roles of exercise and supraspinal reflexes Electroenceph. clin. Neurophysiol. 38: 245-254, 1975.

Milner-Brown, H.S., R.B. Stein and R. Yemm. The orderly recruitment of human motor units during voluntary isometric contractions. J. Physiol (London) 230: 259-270, 1973.

Morpugo, B. Ueber Activitats - Hypertrophie der willkurlicken Muskeln. Virchows Arch.150: 522-544, 1897.

Muller, E.A. Influence of training and of inactivity on muscle strength. Arch.Phys.Med. Rehab.51: 449-462, 1970.

Muller, E.A. and H. Beckmann. Die Trainierbarkeit von Kindern mit gelähmten Muskeln durch isometrishe Kontracktionen. Z. Orthop.102: 130-145, 1966.

Muller, E.A. and W. Rohmert. Die Geschwindigkeit der Muskeldraft - Zunahme bei isometrischen Training. Int Z angew Physiol 19: 403-419, 1963.

Padykula, H.A. and E. Herman. The specificity of the histochemical method for adenosine triphosphatase. J. Histochem. cytochem 3: 170-183, 1955.

Piehl, K. Glycogen storage and depletion in human skeletal muscle fibers. Acta Physiol. Scand. Suppl. 402: 1-33, 1974.

Prince, F.P., R.S. Hikida and F.C. Hagerman. Human muscle fiber types in power lifters, distance runners and untrained subjects. Pflügers Arch. 363: 19-26, 1976.

Rasch, P.J. Some Aspects of muscular movement: a review. Amer. Correct. Ther. J. 23: 151-153, 1969.

Sica, R.E.P. and A. J. McComas. Fast and slow twitch units in a human muscle. J. Neurol. Neurosurg. Phychiat.34: 113-120, 1971.

Siebert, W. Untersuchungen uber Hypertrophie des Skelletmuskels Klin. Med. 109: 350-359, 1928.

Simon, J.N.M. Dispositif de contention des électrodes de stimulation pour l'étude du réflexe de Hoffman chez l'homme. Electroenceph. Clin. Neurophysiol.supp. 22: 174-176, 1962.

Smorto, M.P. and J.V. Basmajian. Clinical Electroneurography. The Williams and Wilkins Co. Baltimore, 1972.

Staudte, H.W., G.U. Exner and D. Pette. Effects of short term, high intensity (sprint) training on some conctractile and metabolic characteristics of fast and slow muscle of the rat. Pflügers Arch. 344: 159-168, 1973.

Susheela, A.K. and J.N. Walton. Note on the distribution of histochemical fibre types in some normal human muscles. J. Neurol.Sci 8: 201-207, 1969.

Syrovy, I., E. Gutmann and J. Melichna. Effect of exercise on skeletal muscle myosin ATPase activity. Physiol. Bohemos. 21: 633-638, 1972.

Veale, J.L., R.F. Mark and S. Rees. Differential sensitivity of motor and sensory fibres in human ulnar nerve. J. Neurol. Neurosurg. Psychiat. 36: 75-86, 1973.

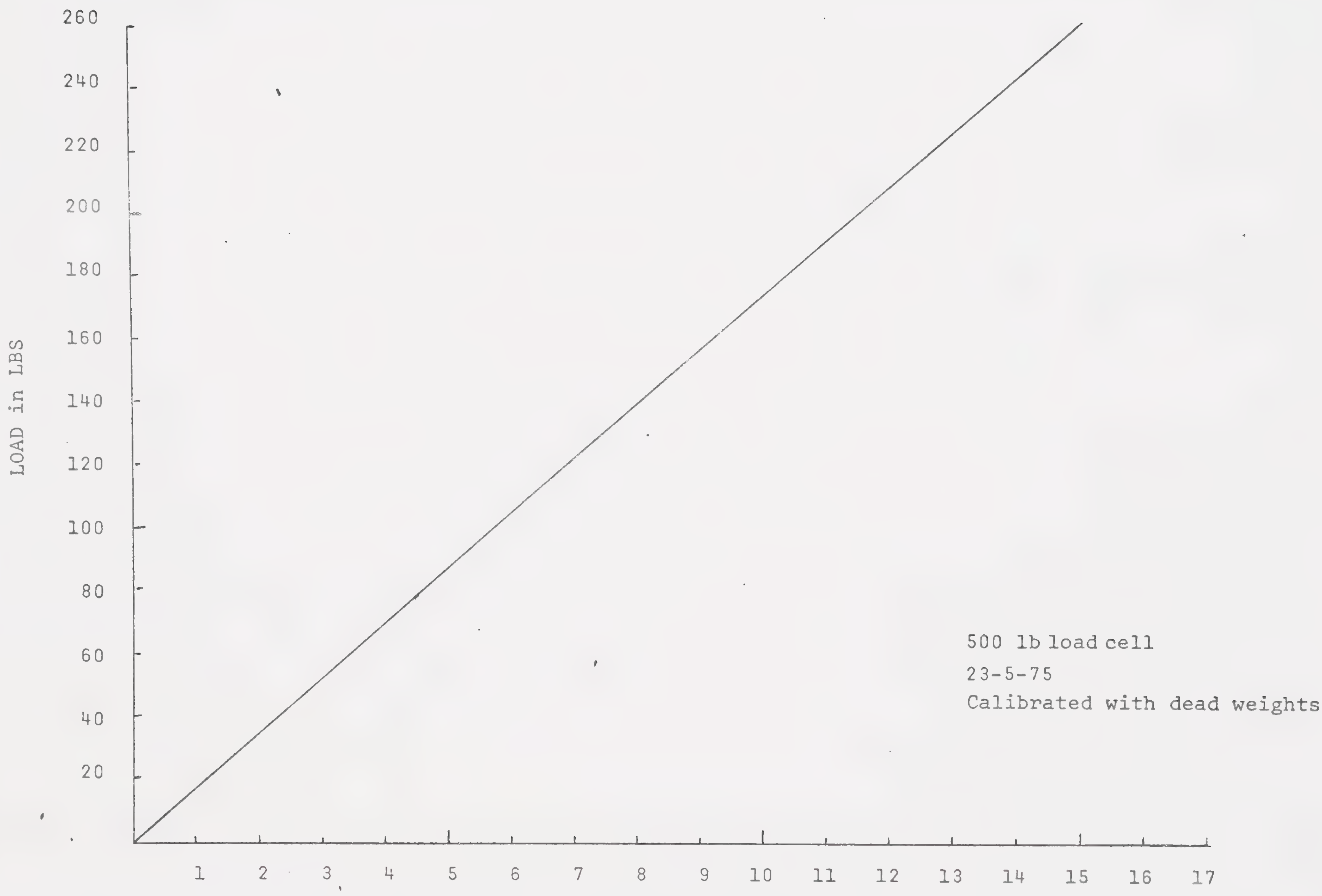
Veale, J.L., S. Rees and R. F. Mark. Renshaw cell activity in normal and spastic man. In New Developments in Electromyography and Clinical Neurophysiology, edited by J.E. Desmedt, Vol. 3, pp. 523-537 (Karger, Basel 1973).

Wagman, T.H., D.S. Pierce and R.E. Brugher. Proprioceptive influences in volitional control of individual motor units. Nature (London) 207: 957-958, 1965.

Winer, B.J. Statistical principles in experimental design. McGraw-Hill, New York, 1971.

APPENDIX A

CALIBRATION OF LOAD CELL


LOAD in LBS
260
240
220
200
180
160
140
120
100
80
60
40
20
1
2
3
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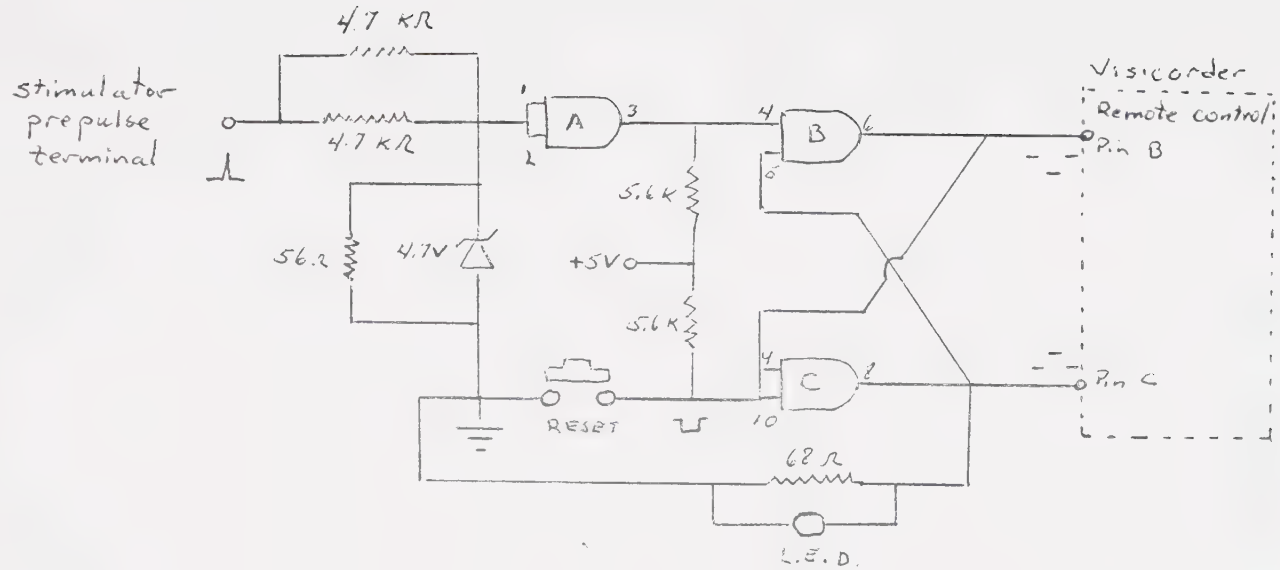
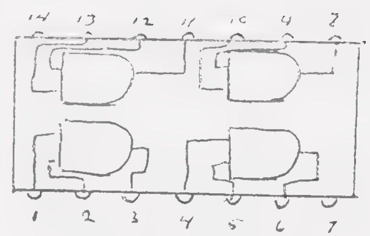
5
6
7
8
9
10
11
12
13
14
15
16
17
500 lb load cell
23-5-75
Calibrated with dead weights

APPENDIX B

RELAY CIRCUIT





Gilles Lessard
October 8, 1975

APPENDIX C

WEIGHTLIFTERS ANTHROPOMETRIC DATA

AND PERFORMANCE

WEIGHTLIFTERS, ANTHROPOMETRIC DATA

AND PERFORMANCE

	Height (inches)	Weight (pounds)	Clean and Jerk (pounds)	Training experience (years)
M. Cardinal	78	262	400	2
M. Kushmen	68	194	325	1.5
G. Matthew	70	200	350	6
D. Robitaille	66	165	385	3
Mean	70.5	205.2	365	3.1

APPENDIX D

INDIVIDUAL DATA

(Study I: physical education students)

Name Jean Bernier #1

Group Control

			Trials							
			1	2	3	4	5	$\bar{X}$		
PRE		Peak tension	126	132	136	138	137	133.8	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	121	118	117	118	118	118.4	CT	M
		Half-relaxation	88	80	86	86	91	86.2	HT	
		Twitch tension	13.5	13.5	13.5	13.5	13.5	13.5	TT	
POST		Peak tension	106	103	101	112	118	108	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	126	123	129	129	129	127.2	CT	M
		Half-relaxation	58	66	66	64	60	62.8	HT	
		Twitch tension	10.75	10.5	10.5	10.5	10.25	10.5	TT	

Name Jean de la Chevrotière # 2

Group Control

		Trials 1	2	3	4	5	$\bar{X}$		
PRE	Peak tension	124	144	142	164	163	147.4	PT	
H-response	Contraction time	109	108	107	108	109	108.2	CT	H
	Half-relaxation	62	64	63	62	66	63.4	HT	
	Twitch tension	11.5	11.25	11.25	11.75	10.25	11.2	TT	
M-response	Contraction time	94	94	93	94	92	93.4	CT	M
	Half-relaxation	76	76	77	77	78	76.8	HT	
	Twitch tension	16.75	17	17	17.25	17	17	TT	
POST	Peak tension	155	154	162	158	156	157	PT	
H-response	Contraction time	104	102	104	104	103	103.4	CT	H
	Half-relaxation	55	60	59	58	59	58.2	HT	
	Twitch tension	11	11.5	11.75	12	12	11.65	TT	
M-response	Contraction time	94	96	96	95	95	95.2	CT	M
	Half-relaxation	72	68	67	69	67	68.6	HT	
	Twitch tension	15.5	15.5	15.25	15.5	15.5	15.45	TT	

Name Richard Demers # 3

Group Control

		Trials 1	2	3	4	5	$\bar{X}$		
PRE	Peak tension	109	115	119	112	114	113.8	PT	
H-response	Contraction time	118	115	114	116	115	115.6	CT	H
	Half-relaxation	52	53	51	59	59	54.8	HT	
	Twitch tension	6.25	6.26	6.75	5	4.5	5.75	TT	
M-response	Contraction time	81	78	73	80	89	80.2	CT	M
	Half-relaxation	60	62	65	74	64	65	HT	
	Twitch tension	13	13	12.75	13	13	12.95	TT	
POST	Peak tension	138	137	133	131	130	133.8	PT	
H-response	Contraction time							CT	H
	Half-relaxation							HT	
	Twitch tension							TT	
M-response	Contraction time	78	79	78	80	74	77.8	CT	M
	Half-relaxation	82	81	82	80	81	81.2	HT	
	Twitch tension	13	13.25	13.25	13.25	13.25	13.2	TT	

Name André Dorion # 4

Group Control

			Trials 1	2	3	4	5	$\bar{X}$		
PRE		Peak tension	119	105	84	117	120	109	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	90	91	82	90	92	89	CT	M
		Half-relaxation	106	106	112	104	101	105.8	HT	
		Twitch tension	21.5	22	22	22	22.25	21.95	TT	
POST		Peak tension	125	153	145	128	109	132	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	71	68	68	68	70	69	CT	M
		Half-relaxation	87	91	90	92	90	90	HT	
		Twitch tension	20.5	20.5	21	21	21	20.8	TT	

Name Denis Gigoux # 5

Group Control

		Trials 1	2	3	4	5	$\bar{X}$		
PRE	Peak tension	94	111	99	127	108	107.8	PT	
H-response	Contraction time	104	100	100	107	102	102.6	CT	H
	Half-relaxation	44	46	46	45	54	47	HT	
	Twitch tension	10	10	9.75	10	10.25	10	TT	
M-response	Contraction time	110	114	112	101	106	108.6	CT	M
	Half-relaxation	84	80	80	87	87	83.6	HT	
	Twitch tension	16	16.5	16.75	16.25	16	16.3	TT	
POST	Peak tension	143	133	117	112	130	127	PT	
H-response	Contraction time							CT	H
	Half-relaxation							HT	
	Twitch tension							TT	
M-response	Contraction time	96	96	94	94	96	95.2	CT	M
	Half-relaxation			68			"80.82"	HT	
	Twitch tension	13.75	14.25	14	14.25	13.5	13.95	TT	

Name Guy Lacelle # 6

Group Control

			Trials 1	2	3	4	5	$\bar{X}$		
PRE		Peak tension		111	112	107	95	106.25	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	88	90	90	87	89	88.4	CT	M
		Half-relaxation	78	78	80	81	77	78.8	HT	
		Twitch tension	11.5	11.75	11.75	11.75	11.75	11.7	TT	
POST		Peak tension	107	95	89	94	98	96.6	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	81	77	82	82	81	80.6	CT	M
		Half-relaxation	89	90	86	85	89	87.8	HT	
		Twitch tension	9.5	9.5	9.5	9.5	9.5	9.5	TT	

Name Réjean Larouche # 7

Group Control

			Trials 1	2	3	4	5	$\bar{X}$		
PRE		Peak tension	169	178	190	182	181	180	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	116	112	122	121	120	118.2	CT	M
		Half-relaxation	81	90	81	79	81	82.4	HT	
		Twitch tension	17.5	17	17.5	17.5	17.25	17.35	TT	
POST		Peak tension	172	154	166	173	160	165	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	114	119	117	115	118	116.6	CT	M
		Half-relaxation	80	76	76	79	76	77.4	HT	
		Twitch tension	16	16.25	16.25	16.5	16.25	16.25	TT	

Name Léo Marleau # 8

Group Control

		Trials 1	2	3	4	5	$\bar{X}$		
PRE	Peak tension	125	132	139	134	144	134.8	PT	
H-response	Contraction time	115	119	117	118	120	117.8	CT	H
	Half-relaxation	87	88	81	90	75	84.2	HT	
	Twitch tension	4.5	4.25	4.25	4	4.5	4.3	TT	
M-response	Contraction time						"96.56"	CT	Ḿ
	Half-relaxation						"83.48"	HT	
	Twitch tension						"15.72"	TT	
POST	Peak tension	140	146	141	149	149	145	PT	
H-response	Contraction time	102	96	100	98	102	99.6	CT	H
	Half-relaxation	51	56	52	54	51	52.8	HT	
	Twitch tension	6.25	6.25	6.25	6.25	6.5	6.3	TT	
M-response	Contraction time	106	104	106	100	105	104.2	CT	M
	Half-relaxation	68	68	64	68	66	66.8	HT	
	Twitch tension	9.25	9.5	9.5	9.5	9.5	9.45	TT	

Name André Michaud # 9

Group Control

		Trials 1	2	3	4	5	$\bar{X}$		
PRE	Peak tension	116	129	115	109	104	114.6	PT	
H-response	Contraction time							CT	H
	Half-relaxation							HT	
	Twitch tension							TT	
M-response	Contraction time	78	80	76	78	80	78.4	CT	M
	Half-relaxation	78	82	82	85	82	81.8	HT	
	Twitch tension	12.5	12.5	12.5	12.75	12.75	12.6	TT	
POST	Peak tension	114	120	116	118	117	117	PT	
H-response	Contraction time							CT	H
	Half-relaxation							HT	
	Twitch tension							TT	
M-response	Contraction time	79	78	76	78	78	77.8	CT	M
	Half-relaxation	84	82	85	83	82	83.2	HT	
	Twitch tension	13.75	14	14	14	14	13.95	TT	

Name Robert Pontbriand # 10

Group Control

			1	2	3	4	5	$\bar{X}$		
PRE		Peak tension	112	140	135	136	139	132.4	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	110	108	108	109	109	108.8	CT	M
		Half-relaxation	98	101	104	100	103	101.2	HT	
		Twitch tension	11.25	11.25	11.5	11.5	11.5	11.4	TT	
POST		Peak tension	118	118	123	108	114	116.2	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	94	103	98	100	96	98.2	CT	M
		Half-relaxation		107	104	111	114	109	HT	
		Twitch tension	10.75	10.75	10.75	10.75	10.75	10.75	TT	

Name Robert Théroux # 11

Group Control

		Trials 1	2	3	4	5	$\bar{X}$	
PRE	Peak tension	112	109	112	114	126	114.6	PT
H-response	Contraction time	114	112	119	113	112	114	CT
	Half-relaxation	68	72	61	62	62	65	HT H
	Twitch tension	12.25	13	12.5	12.25	13	12.6	TT
M-response	Contraction time	86	84	81	80	80	82.2	CT
	Half-relaxation	69	72	74	75	76	73.2	HT Ḿ
	Twitch tension	22	22.5	22.5	22.75	22.75	22.5	TT
POST	Peak tension	107	107	119	122	114	112.8	PT
H-response	Contraction time	103	107	106	103	100	103.8	CT
	Half-relaxation	54	52	52	55	58	54.2	HT H
	Twitch tension	9.25	10.5	10.75	10.5	10.75	10.35	TT
M-response	Contraction time	76	74	75	76	71	74.4	CT
	Half-relaxation	83	82	81	78	83	81.4	HT M
	Twitch tension	13.5	13.5	13.75	14	14	13.75	TT

Name Réjean Audet # 1

Group Experimental

			Trials 1	2	3	4	5	$\bar{X}$		
PRE		Peak tension	172	181	175	175	182	177	PT	
	H-response	Contraction time	113	198	116	112	112	112.2	CT	H
		Half-relaxation	61	66	72	64	62	65	HT	
		Twitch tension	13	13.5	13.5	12.5	12.75	13.05	TT	
	M-response	Contraction time	91	90	90	92	90	90.6	CT	M
		Half-relaxation	73	78	75	78	78	76.4	HT	
		Twitch tension	22	22.25	22	22	22.25	22.1	TT	
POST		Peak tension	176	165	159	178	195	174.6	PT	
	H-response	Contraction time	102	107	106	107	105	105.4	CT	H
		Half-relaxation	67	57	62	60	63	61.8	HT	
		Twitch tension	9.25	11.25	11.25	11	11.25	10.8	TT	
	M-response	Contraction time	96	102	100	100	100	99.6	CT	M
		Half-relaxation	74	70	72	70	70	71.2	HT	
		Twitch tension	16.5	17	17.25	17.25	17.25	17.05	TT	

Name Mark Cléroux # 2

Group Experimental

			Trials 1	2	3	4	5	$\bar{X}$		
PRE		Peak tension	97	105	119	135	148	120.8	PT	
	H-response	Contraction time	101	96	88	96	93	94.8	CT	H
	H-response	Half-relaxation	75	78	83	76	79	78.2	HT	H
	H-response	Twitch tension	7	8.25	7.5	7.5	7.25	7.5	TT	H
	M-response	Contraction time	105	104	108	110	102	105.8	CT	M
	M-response	Half-relaxation	79	77	73	71	84	76.8	HT	M
	M-response	Twitch tension	9	9	9.25	9.5	10	9.35	TT	M
POST		Peak tension	160	164	164	162	156	161.2	PT	
	H-response	Contraction time	106	105	108	112	111	108.4	CT	H
	H-response	Half-relaxation	50	56	54	50	51	52.2	HT	H
	H-response	Twitch tension	7	7	6.5	7.75	7.75	7.2	TT	H
	M-response	Contraction time	98	96	93	94	93	94.8	CT	M
	M-response	Half-relaxation	71	66	70	68	72	69.4	HT	M
	M-response	Twitch tension	10.75	11.5	11.75	11.75	12	11.55	TT	M

Name Jacques Drapeau # 3

Group Experimental

		Trials 1	2	3	4	5	$\bar{X}$		
PRE	Peak tension	119	108	142	155	149	134.6	PT	
H-response	Contraction time							CT	H
	Half-relaxation							HT	
	Twitch tension							TT	
M-response	Contraction time	98	98	98	96	98	97.6	CT	$\acute{M}$
	Half-relaxation	83	83	83	86	83	83.6	HT	
	Twitch tension	14.75	14.75	14.25	14.25	14.75	14.55	TT	
POST	Peak tension	150	177	176	180	174	171.4	PT	
H-response	Contraction time	84	82	82	81	81	82	CT	H
	Half-relaxation	82	85	88	85	89	85.8	HT	
	Twitch tension	3.5	3.5	4.5	4	4.25	3.95	TT	
M-response	Contraction time	90	91	88	86	86	88.2	CT	M
	Half-relaxation	82	81	82	85	84	82.8	HT	
	Twitch tension	11	11.75	11.75	11.75	11.5	11.55	TT	

Name Jean Duchesne # 4

Group Experimental

			Trials						
		1	2	3	4	5	$\bar{X}$		
PRE	Peak tension	150	141	137	135	141	140.8	PT	
H-response	Contraction time	88	88	87	87	88	87.6	CT	H
	Half-relaxation	66	70	75	73	72	71.2	HT	
	Twitch tension	7.25	8.5	8.25	8	8	8	TT	
M-response	Contraction time	78	77	78	78	79	78	CT	M
	Half-relaxation	80	77	82	90	83	82.4	HT	
	Twitch tension	10.25	10.25	10	10.5	10.25	10.25	TT	
POST	Peak tension	146	138	138	133	140	139	PT	
H-response	Contraction time							CT	H
	Half-relaxation							HT	
	Twitch tension							TT	
M-response	Contraction time		92	93	92	93	92.5	CT	M
	Half-relaxation		66	69	68	71	68.5	HT	
	Twitch tension		7.25	8	7.75	7.75	7.69	TT	

Name Serge Gravel # 5

Group Expérimental

		Trials 1	2	3	4	5	$\bar{X}$		
PRE	Peak tension	177	182	172	176	185	178.4	PT	
H-response	Contraction time	108	109	112	108	109	109.2	CT	H
	Half-relaxation	84	83	86	90	83	85.2	HT	
	Twitch tension	8	8	7.75	8.25	8.5	8.1	TT	
M-response	Contraction time	104	106	104	103	104	104.2	CT	M
	Half-relaxation	79	81	81	85	84	82	HT	
	Twitch tension	13	13.25	13.5	13.5	13.25	13.3	TT	
POST	Peak tension	166	170	168	157	163	164.8	PT	
H-response	Contraction time							CT	Π
	Half-relaxation							HT	
	Twitch tension							TT	
M-response	Contraction time	94	93	94	93	94	93.6	CT	M
	Half-relaxation	93	91	89	91	88	90.4	HT	
	Twitch tension	12.75	12.75	12.75	12.75	12.75	12.75	TT	

Name Marcel Lacroix # 6

Group Experimental

			Trials 1	2	3	4	5	$\bar{X}$		
PRE		Peak tension	159	170	193	201	197	184	PT	
	H-response	Contraction time	96	98	96	96	96	96.4	CT	H
		Half-relaxation	66	68	71	71	70	69.2	HT	
		Twitch tension	10.5	11.5	11.5	10.75	11	11.05	TT	
	M-response	Contraction time	85	86	89	92	90	88.4	CT	M
		Half-relaxation	87	91	94	96	93	92.2	HT	
		Twitch tension	15.25	15	14.25	14.25	14.25	14.6	TT	
POST		Peak tension	143	135	141	130	136	137	PT	
	H-response	Contraction time	82	82	84	84		83	CT	H
		Half-relaxation	61	62	61	60		61	HT	
		Twitch tension	11.75	11.75	12	12		11.87	TT	
	M-response	Contraction time	80	80	84	80	76	80	CT	M
		Half-relaxation	76	80	76	80	84	79.2	HT	
		Twitch tension	14	14.25	14.25	13.75	14	14.05	TT	

Name Mario Lafortune # 7

Group Experimental

		1	2	3	4	5	$\bar{X}$	
PRE	Peak tension	161	145	148	145	157	151.2	PT
H-response	Contraction time							CT H
	Half-relaxation							HT H
	Twitch tension							TT H
M-response	Contraction time	89	90	90	86	88	88.6	CT M
	Half-relaxation	101	100	100	104	102	101.4	HT M
	Twitch tension	16.5	16.75	16.5	16.5	16.5	16.55	TT M
POST	Peak tension	152	155	155	155	158	155	PT
H-response	Contraction time							CT H
	Half-relaxation							HT H
	Twitch tension							TT H
M-response	Contraction time	94	96	93	96	95	94.8	CT M
	Half-relaxation	77	78	78	76	75	76.8	HT M
	Twitch tension	16.25	16.5	16.5	16.5	16.5	16.45	TT M

Name Jean Lépine # 8

Group Experimental

			Trials 1	2	3	4	5	$\bar{X}$		
PRE		Peak tension	113	122	128	127	130	124	PT	
	H-response	Contraction time	96	101	102	101	100	100	CT	H
		Half-relaxation	59	54	52	54	54	54.6	HT	
		Twitch tension	11.25	11	11.25	11.5	11.25	11.25	TT	
	M-response	Contraction time	85	86	86	85	85	85.4	CT	M
		Half-relaxation	71	68	70	71	70	70	HT	
		Twitch tension	16.75	16.75	16.75	16.75	16.75	16.75	TT	
POST		Peak tension	120	119	118	118	130	121	PT	
	H-response	Contraction time	106	110	108	108	107	107.8	CT	H
		Half-relaxation	62	62	63	68	64	63.8	HT	
		Twitch tension	8.25	8.25	8.25	8	8.5	8.25	TT	
	M-response	Contraction time	92	90	90	89	88	89.8	CT	M
		Half-relaxation	74	77	76	77	76	76	HT	
		Twitch tension	11	11.25	11.25	11.25	11.5	11.25	TT	

Name Jean Ménard # 9

Group Experimental

			Trials 1	2	3	4	5	$\bar{X}$		
PRE		Peak tension	106	107	108	102	105	105.6	PT	
	H-response	Contraction time	88	91	89	88	90	89.2	CT	H
		Half-relaxation	56	55	55	57	52	55	HT	
		Twitch tension	6.25	6.25	5.75	5.75	6	6	TT	
	M-response	Contraction time	77	80	80	80	78	79	CT	M
		Half-relaxation	67	71	74	73	75	72	HT	
		Twitch tension	8	7.75	7.75	8	8	7.9	TT	
POST		Peak tension	98	93	91	88	86	91.2	PT	
	H-response	Contraction time	78	81	77	79	82	79.4	CT	H
		Half-relaxation	64	60	65	63	60	62.4	HT	
		Twitch tension	6.5	6.75	6.5	6.75	6.5	6.6	TT	
	M-response	Contraction time	88	86	89	88	86	87.4	CT	M
		Half-relaxation	78	79	75	76	78	77.2	HT	
		Twitch tension	9	9	8.75	9	8.75	8.9	TT	

Name Jean-Marie Messier # 10

Group Experimental

			Trials						
		1	2	3	4	5	X̄		
PRE	Peak tension	145	145	138	139	144	142.2	PT	
H-response	Contraction time	122	128	122	120	120	122.4	CT	H
	Half-relaxation	75	78	78	78	76	77	HT	
	Twitch tension	10.5	12.75	12.25	12.25	12.5	12.05	TT	
M-response	Contraction time	115	114	112	113	110	112.8	CT	M
	Half-relaxation	87	84	84	85	86	85.2	HT	
	Twitch tension	15	14.75	14.75	14.75	14.75	14.8	TT	
POST	Peak tension	131	122	125	126	132	127.2	PT	
H-response	Contraction time	108	108	108	107	107	107.6	CT	H
	Half-relaxation	68	67	66	65	65	66.2	HT	
	Twitch tension	6.75	8.5	10	9.25	9.25	8.75	TT	
M-response	Contraction time	116	116	117	116	114	115.8	CT	M
	Half-relaxation	62	60	59	59	60	60	HT	
	Twitch tension	15.25	15.25	15	15	15.25	15.15	TT	

Name Jean Otis # 11

Group Experimental

		1	2	3	4	5	X̄		
PRE	Peak tension	180	169	172	174	169	172.8	PT	
H-response	Contraction time	98	103	108	111	108	105.6	CT	H
	Half-relaxation	62	68	62	58	59	61.8	HT	
	Twitch tension	22.5	20	21	21.5	21.75	21.35	TT	
M-response	Contraction time	96	97	98	96	94	96.2	CT	M
	Half-relaxation	72	69	67	68	72	69.6	HT	
	Twitch tension	23.5	23.75	23.75	24.25	24.75	24	TT	
POST	Peak tension	220	200	215	192	205	206.4	PT	
H-response	Contraction time							CT	H
	Half-relaxation							HT	
	Twitch tension							TT	
M-response	Contraction time	97	95	96	96	95	95.8	CT	M
	Half-relaxation	52	53	51	52	53	52.2	HT	
	Twitch tension	27.75	28	28	28.5	28	28.05	TT	

APPENDIX E

INDIVIDUAL DATA

(Study II: sedentary subjects)

Name Jean Compain # 1

Group Control

		Trials 1	2	3	4	5	$\bar{X}$		
PRE	Peak tension	100	122	112	127	127	117.6	PT	
H-response	Contraction time							CT	H
	Half-relaxation							HT	
	Twitch tension							TT	
M-response	Contraction time	125	122	123	122	121	122.6	CT	M
	Half-relaxation	87	88	85	88	85	86.6	HT	
	Twitch tension	15.9	16.5	16.5	16.4	16	16.26	TT	
POST	Peak tension	107	120	115	125	122	117.8	PT	
H-response	Contraction time							CT	H
	Half-relaxation							HT	
	Twitch tension							TT	
M-response	Contraction time	108	108	109	108	106	107.8	CT	M
	Half-relaxation	89	86	85	84	86	86	HT	
	Twitch tension	15.9	16.5	16.4	16.3	16.6	16.34	TT	

Name Jean Duval # 2

Group Control

			Trials 1	2	3	4	5	$\bar{X}$		
PRE		Peak tension	93	97	88	87	83	89.6	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	105	103	102	105	94	101.8	CT	M
		Half-relaxation	80	75	76	77	79	77.4	HT	
		Twitch tension	10.4	10.2	10.2	10.5	10.1	10.28	TT	
POST		Peak tension	121	117	105	113	112	113.6	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	120	116	114	117	115	116.4	CT	M
		Half-relaxation	66					66	HT	
		Twitch tension	14	13.8	13.6	13.8	13.8	13.8	TT	

Name Denis Gaudreau #3

Group Control

			Trials 1	2	3	4	5	X̄		
PRE		Peak tension	87	87	87	78	83	84.4	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	98	92	67	68	67	78.4	CT	M
		Half-relaxation	90	88	101	102	103	96.8	HT	
		Twitch tension	7.9	8.1	8.1	8.2	8.2	8.1	TT	
POST		Peak tension	95	113	88	90	90	95.2	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	84	84	82	82	82	82.8	CT	M
		Half-relaxation	95	96	100	97	98	97.2	HT	
		Twitch tension	7.5	7.5	7.5	7.5	7.2	7.44	TT	

Name Garry Sellars # 4

Group Control

		Trials 1	2	3	4	5	X̄	
PRE	Peak tension	83	88	74	100	96	88.2	PT
H-response	Contraction time							CT
	Half-relaxation							HT
	Twitch tension							TT
M-response	Contraction time	106	105	107	104	107	105.8	CT
	Half-relaxation	63	65	61	64	60	62.6	HT
	Twitch tension	5.2	5.5	5.6	5.5	5.5	5.46	TT
POST	Peak tension	101	106	97	97	104	101	PT
H-response	Contraction time							CT
	Half-relaxation							HT
	Twitch tension							TT
M-response	Contraction time	104	103	103	102	103	103	CT
	Half-relaxation	64	63	63	62	62	62.8	HT
	Twitch tension	6.9	6.9	6.8	6.7	6.8	6.82	TT

Name Pierre Benoit # 1

Group Experimental

		Trials 1	2	3	4	5	$\bar{X}$	
PRE	Peak tension	102.5	61	77.5	80	89	82	PT
H-response	Contraction time							CT
	Half-relaxation							HT H
	Twitch tension							TT
M-response	Contraction time	82	85	84	84	83	83.6	CT
	Half-relaxation	86	85	85	86	86	85.6	HT M
	Twitch tension	9	9	9.1	9.1	9	9.04	TT
POST	Peak tension	121	123	122	125	128	123.8	PT
H-response	Contraction time							CT
	Half-relaxation							HT H
	Twitch tension							TT
M-response	Contraction time	94	94	94	95	94	94.2	CT
	Half-relaxation	68	72	72	71	72	71	HT M
	Twitch tension	11	11	11	11	11	11	TT

Name Léonard Bertrand # 2

Group Experimental

			Trials 1	2	3	4	5	$\bar{X}$		
PRE		Peak tension	79.5	82.5	90	80	100	86.4	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	77	77	76	76	73	75.8	CT	M
		Half-relaxation		87	94	94	87	90.5	HT	
		Twitch tension	9	8.7	9	9.1	9.1	8.98	TT	
POST		Peak tension	118	117	117	115	111	115.6	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	79	87	87	88	88	85.8	CT	M
		Half-relaxation	85	79	79	78	76	79.4	HT	
		Twitch tension	12.9	12.9	12.8	12.9	12.9	12.88	TT	

Name Denis Blais # 3

Group Experimental

			Trials 1	2	3	4	5	$\bar{X}$		
PRE		Peak tension	87.5	95	93	104	103.5	96.6	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	119	121	118	118	119	119	CT	M
		Half-relaxation	110	107	110	109	110	109.2	HT	
		Twitch tension	9.8	10.1	10	10.2	10.4	10.1	TT	
POST		Peak tension	120	126	125	125	125	124.2	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	114	114	113	115	115	114.2	CT	M
		Half-relaxation	93	90	91	88	88	90	HT	
		Twitch tension	9.6	9.6	9.2	9.2	9.2	9.2	TT	

Name Jacques Fortin # 4

Group Experimental

			Trials 1	2	3	4	5	$\bar{X}$		
PRE		Peak tension	118.5	118.5	112	118.5	116	116.7	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	72	72	72	72	74	72.4	CT	M
		Half-relaxation	33	84	83	82	80	82.4	HT	
		Twitch tension	9.7	9.6	9.6	9.7	9.8	9.68	TT	
POST		Peak tension	128	127	122.5	122	122.5	124.4	PT	
	H-response	Contraction time							CT	H
		Half-relaxation							HT	
		Twitch tension							TT	
	M-response	Contraction time	94	93	94	94	93	93.6	CT	M
		Half-relaxation	61	63	62	61	61	61.6	HT	
		Twitch tension	11.8	11.9	11.8	11.8	11.8	11.82	TT	